Milk Production in Developing Countries

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THE PLANNING OF MILK PRODUCTION IN INDIA

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TO
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INTRODUCTION

Review of the Problems

As we approach the 1970's it would be well to review some of the problems of human ecology and nutrition with which planners of development are now faced. The four words, famine, starvation, hunger and malnutrition are used, sometimes accurately, sometimes loosely, to describe the situation which some countries have reached now and which many more are likely to reach in the not far distant future. Hunger, starvation and famine relate primarily to shortage of the major food grains, wheat, rice, maize and the millets, which are needed 'to fill the bellies' of peoples living on a subsistence diet or on low planes of nutrition. Malnutrition refers to an unbalanced diet, lacking in those proteinaceous foods that provide the essential amino acids, and in the protective foods that provide the vitamins. We should consider briefly what can be done to meet the present and future situations in terms of land use, agriculture and animal husbandry in the equatorial, tropical and subtropical environments.

In the past, famine and starvation were recognizable because they could be measured in terms of human lives or readily visible forms of human suffering. Today they still threaten, but can be predicted and averted by international action. They become the subject of newspaper headlines and of cynical political exploitation. The nature and causes of famines are difficult to establish and define: they may actually be the result of a disastrous crop failure due to drought or an epidemic of plant diseases, or to pests and rodents. Population may have outstripped production. Industrial development may have increased the purchasing power of one section of the community causing increased pressure on, and a rise in price of, food grains in the absence of an adequate alternative market in animal products to serve as an outlet.

Shortages may arise in abnormal years in some parts of a country because certain provinces or states, in self-defence, intentionally underestimate their surpluses, while others overestimate their deficits. Regional communities may be conservative in their dietary preferences

and be unwilling to change, for example, from rice to wheat. Famine or starvation will occur in an urban population when the rural producers ensure that their own families shall not suffer—they will store a two-year reserve of food grains under the floor or in earth-covered pits out of doors exposed to insects and rodents, rather than assist urban consumers by converting their grain into money, which cannot purchase unavailable food. It is very difficult to promote a social conscience much beyond the family level in the face of widespread shortage of food, real or threatened.

Malnutrition is much more widespread, insidious but not so readily visible, or at least not so recognizable unless one has eyes trained to see and to interpret the evidence. Those who die first in famines will, of course, be the people suffering most from malnutrition, but these are only a small percentage of the total of undernourished. Malnutrition is measured in non sensational terms which do not make the headlines and do not provide fodder for politicians—general physical stature, well-being and energy of the people and particularly of the young, growth rates, capacity of women to rear children without seriously undermining their own health, deaths in infants under twelve months and of children from one to five years of age, resistance to disease, and so on. After a survey of the rural areas in a south Indian state in February 1966, a team from the Government of India Planning Commission concluded that 'there was no sign of actual or impending famine and little sign of malnutrition'. In November 1965, an FAO Nutrition Adviser had visited the same areas and stated that every child in the village schools showed signs of malnutrition to a greater or lesser extent.

Two Levels of Nutrition

It is with the correction of malnutrition that the planner of milk production is primarily concerned. In planning agriculture and animal husbandry for the reduction of malnutrition, we must recognize that this is the second and more difficult stage of a two-stage process.

Stage 1 has the limited objective of holding back hunger and famine by increasing yield per acre and total production of food grains to a maximum. This is done by schemes and action directed towards what is sometimes called intensification of agriculture. Such action involves increased use of fertilizers, the use of seeds of better varieties of cereals in particular, the control of pests and diseases, and the development of irrigation. This is the realm of departments of agriculture, the officers

of which assume that whatever animal products are also to be made available to the people shall be produced on non-agricultural land; their precious crop land shall not be available for the cultivation of green fodder crops or the ingredients of concentrates.

The economics of Stage 1 are based on specialization in near-continuous cropping of cereals with ample use of fertilizers to maintain a supply of plant nutrients. From the human nutritional point of view, this is a short-sighted policy. Those who preach and practise this policy for their economic ends contribute only to the arrest of hunger and famine through the supply of quantity at the expense of quality. Some countries in favourable ecoclimates can afford to adopt such a policy for certain regions, on the assumption that the animal protein balance necessary in the human nutrition shall be provided by temperate pastures and fodder crops in other regions or by import from other parts of the world.

Stage 2 is the one reached by most of the developed countries; it is still a rather dim target in many of the developing countries which, for obvious reasons, cannot see and plan much beyond the first hurdle of quantity. Stage 2 is based upon correct principles of human nutrition, whereby the whole population should have available a certain amount of animal protein in order that they may receive the essential amino acids. To achieve rather hazy objectives, many developing countries are supporting development of the dairy, poultry and pig industries, without having calculated where the feeds and fodders or the livestock are to come from.

The logical sequel, the introduction of an appropriate form of mixed farming, alternate husbandry or the integration of crop and animal husbandry on the same land, may be correct in terms of human nutrition, but it is regarded as old-fashioned and uneconomic by the school that preaches more fertilizers without the redesign of farming systems and crop rotations. Thus development in general is at present at Stage 1, with certain token adventures into Stage 2, to supply milk and dairy produce, eggs and other items to the small, favoured percentage of a population with an adequate purchasing power. Greater awareness of this situation at the planning and policy levels would make it possible to prove whether and to what extent Stage 2 may be achieved, before increase in population reduces this possibility of development towards balanced human nutrition.

Resources for Stage 1

An administrator faced with conditions of chronic starvation or with sudden seasonal famines takes all possible short-term actions to find food grains on the world market for import, and at the same time to step up domestic production of cereal crops Since the latter changes cannot be brought about quickly, there will necessarily be increased reliance for some time at least on importation of food, but on 10th February 1966, President Johnson told Congress 'Candour requires that I warn you the time is not far off when all the combined production on all the acres of all the agriculturally productive nations will not meet the food needs of the developing nations—unless present trends are changed To continue in the old ways could only postpone disaster for a decade Massive shipments would be faced by an ever growing deficit of the hungry nations, because of the growth of population and inefficient agriculture Ultimately those nations would have to pay an exorbitant price They would pay it not only in money but in years and lives wasted If our food aid programmes serve only as a crutch they will encourage the developing nations to neglect improvements they must make in their own production of food'

Those who live and work in a country like India, with an annual deficit of food grains that is periodically aggravated by the failure of one or both of the wet monsoons, are necessarily very conscious of matters relating to the world availability of cereal grains Before the second World War, in 1934–8, there were six grain-exporting regions (North America, Latin America eastern Europe and the Soviet Union, Africa, Asia and Australia), and one importing region (western Europe) Today it appears that there are only two exporting regions (North America and Australia) Reliance upon the availability of wheat must be judged in relation to the level of current exports (56,500 000 metric tons of wheat in 1965–6), the size of wheat stocks (39 million tons by mid-1966 or only 6 or 7 million tons above a 'normal level regarded as essential for safety), the possibility of rapid increases in production (North America may increase by over 50 per cent by bringing land retired from cultivation back into production, Australia is nearing its maximum exporting capacity), and the decisions of national governments and the International Wheat Council with regard to the need for increased production In February 1966, President Johnson asked Congressional approval for holding 60 million acres of uncultivated land

as a food and fibres reserve and added: 'We will bring these acres back into production as needed—but not to produce unwanted surpluses and not to supplant the efforts of other countries to develop their own agricultural economies.' Later, in 1966, the return of part of the food and fibres reserve into cultivation was approved.

It must be realized, for example, that India now (1965) requires 20 per cent of the total wheat production of the United States of America, and it has been stated that this requirement will increase to 50 per cent of the total American production by 1970. In view of this situation and because of the general shortage of foreign exchange in a number of deficit countries, it is natural that everything is being and should be done to step up domestic production of food grains as much and as quickly as possible.

Resources for Stage 2

The countries in which a large proportion of the population lives under conditions of chronic or temporary malnutrition are far more numerous than those in the famine-susceptible class. Their administrations have to decide to what extent it may be practical and realistic to undertake further actions leading to Stage 2—those long-term changes in land use systems which will provide a diet for the whole population which is adequate not only in quantity but also in quality. These changes demand above all a great increase in the amount and quality of foods of animal origin from the land, namely, milk and milk products, pig and poultry products, mutton and beef. The feeding of the livestock to provide these introduces competition for land resources in varying degree. The feeds and fodders required for milch animals, pigs and poultry in the tropics and subtropics must be produced primarily from cultivated land together with and in direct competition with food and cash crops. Meat and beef may be produced from uncultivated and/or uncultivable land, with little or no competition with food crops.

It is with the production of milk as one of the main items in Stage 2 that the present review is primarily concerned. Is it possible to provide or to produce sufficient quantities of milk and dairy products for the population of the developing countries, considering their requirements for them in relation to supplies available from other sources of plant and animal protein, for example, grain legumes, eggs and poultry products, and the various types of meat? It is, of course, incorrect to

attempt such a review in relation to the production of milk and milk products alone Similar reviews should be done for beef cattle, pigs, poultry, sheep and goats, on the basis of the availability of land and the economic viability of and balance between these types of animal production But above all these studies must be made in relation to the production of food crops for direct human consumption, and of cash crops for domestic use or export

No specialist in animal production or in pasture and fodder development can afford to be party to what in certain developing countries would appear to be a somewhat exaggerated emphasis on the importance of applying fertilizers only to cereal crops to provide grains for use as human food The animal production people and the human nutritionists must combine forces and argue and prove the unfashionable thesis that the real criterion of intensification of production from cultivated land is the maximum production of human foods correctly balanced in terms of carbohydrates and proteins of plant and animal origin This will demand the evolution of new farming systems, especially on the very best irrigated land, in which soil structure, organic matter content, nitrogen content and water-holding capacity are provided by rotations with pasture and fodder crops and the full return of dung and urine to the cultivated land It must then be argued that it is upon such soil that fertilizers will give their greatest and most economic effects in terms of increased yield of food crops for direct human consumption and of cash crops, thus making it possible to release land for the production of feeds and fodders Only in this way will it be possible to ensure both freedom from hunger *per se*, and the provision of a ration correctly balanced in terms of calories, proteins of different origin, and vitamins

Protein in Human Nutrition

Food serves two major functions in human nutrition, to provide energy, and to furnish the elements essential for growth and for the replacement of body tissues All of the three main forms of food—carbohydrates, fat and protein, provide the energy, but it is only protein that can supply the nitrogen and amino acids necessary for growth and replacement A Joint Expert Committee of WHO and FAO recently stated that 'perhaps the most important nutritional problem that is still not fully solved is that of meeting the protein requirements of man' and that 'protein nutrition for young children is the main nutritional prob-

lem of the world, and protein malnutrition, if both its direct and indirect effects are considered, is the major cause of ill health'.

A statement in the WHO *Chronicle* for October 1965 shows that on the available evidence, which is far from complete, between 1 and 9 per cent of the child population up to the age of five years in developing countries suffer from 'severe protein caloric deficiency disease', while it is estimated that from 30 to 60 per cent of children between the ages of one to five years suffer from mild to moderate protein deficiency. Infants in the developing countries are relatively immune from protein deficiency as they are practically all breast-fed, but women in those poorer areas are able to sustain such a production of milk only at considerable cost to their own health. After weaning, the foods which are provided to the child are usually prepared from cereals, tubers and plantains, and fed as gruels, and they are much less efficient sources of protein than milk.

A serious complicating factor mentioned in the same report is that unhygienic feeding practices and a poor state of environmental sanitation lead to repeated attacks of intestinal and respiratory infections. This increases the protein loss and depresses the appetite. Food intake is further and often drastically restricted and the child may enter a state of acute protein deficiency and endure all its consequences. As a result, the mortality among children aged one to four years in countries where the diet of the child during and after the weaning period is seriously deficient in protein is twenty to fifty times higher than in western Europe. Growth rates of children in developing countries therefore deviate sharply from the normal at the time of weaning and continue at a low level throughout the entire period of growth, resulting in stunted adult stature. There is also some evidence to suggest that protein malnutrition in the first two years of life may also retard psychomotor development.

It is well know that, in terms of biological value for human nutrition, egg protein heads the list, closely followed by the protein of milk. Egg or milk protein can furnish all the amino acids essential for normal growth and healthy life processes, provided that they are consumed in adequate amounts. Fish, meat and other poultry products are also high in the scale of biological value. A fact of particular importance to the nutritional and agricultural policy of tropical countries is that the vegetable proteins provided by wheat, maize, rice, beans and nuts are of distinctly lower value. They may contain all the necessary amino acids, but one or more of the essential amino acids are present in such

inadequate amounts that the entire protein is of low biological value when it represents the only source of amino acids in the human diet. Thus, incomplete vegetable proteins need to be supplemented with other foods of animal origin which provide the missing amino acids essential for good human nutrition It is nevertheless possible to provide a diet of correctly chosen plant proteins of sufficiently divergent composition, to ensure that the entire spectrum of essential amino acids is supplied This has been done in Latin America, where a combination of maize, soybean, defatted cotton-seed meal, torula yeast, calcium carbonate and vitamin A is now being produced on a commercial scale

Overall Objectives

There has in recent years been a great effort on the part of advanced countries in temperate environments to promote or to assist in the promotion of dairy production in developing countries, especially in the tropics and subtropics Large sums of money and a great deal of expertise have been made available under international and bilateral aid programmes The overall objective has been to provide a cheap and reliable, if limited, source of animal protein to populations living, for one reason or another, on diets composed primarily of carbohydrates

This benevolence on the part of the milk producing donor country is usually confined to providing the equipment for milk-processing factories with their ancillary collection points, chilling centres, and systems of transport and distribution, and to making available personnel experienced in the assembly and initial management of milk plants Any survey that may have preceded the decision to provide these facilities has generally been limited to a study of the nutritional status and demands of the community it is desired to serve, and of the economic problems of marketing and distribution As far as the production of milk is concerned, the common belief, stated or otherwise, was until recently that 'you erect a milk plant and the milk will flow' Experience has now shown that this is not necessarily so, and that equal attention should be given to all factors related to increased production of milk in these new environments, during the phases 'up to the bucket', if the milk factory is to achieve its planned throughput in the reasonably near future

Over much of the tropics, there is competition for limited land resources of cultivable land, and difficulty in providing for the integration of crops and livestock in the land use and farming systems on

which dairy development should be based. Planners must decide whether it is realistic and profitable to attempt to produce milk in places where there are already not enough calories or grams of protein from plants for direct consumption by human beings—whether the land, water and skill needed to produce the fodder would not be better used to feed humans directly. The relative efficiency of bovines, pigs and chickens as converters of limited feed resources into animal proteins should also be considered. This introduces matters related to the special merits of animal, as distinct from vegetable, protein, and of different types of animal proteins (with or without the associated vitamin B12), which are considered desirable even in relatively small amounts, particularly for the so-called vulnerable sections of the community—pregnant and nursing mothers and young children.

Criteria for Dairy Development

It is probable that, in planning as we now must for the feeding of the rapidly increasing population of the coming decades, the inevitable trend will be increasingly towards foods for direct human consumption and away from animal proteins produced wastefully through the body of a bovine. The populations of India and the countries of south-east Asia are expected to double in the next thirty-five years. Perhaps the years immediately ahead represent the only and last chance to establish dairy farming as a permanent component of farming systems. As pressures on land resources increase, dairy farming may well disappear again in favour of farming systems based on cereals and grain legumes. The question that arises, especially when land resources are already limited, is whether there is still time and the necessary room to manœuvre. When defining the criteria for dairy development, we need to have parallel studies on the ecological, technical and economic bases for beef cattle, sheep and goats. All of these can make greater use of natural and generally uncultivable grazing lands than the dairy industry and pig and poultry production, and so are less susceptible to increasing competition with food and cash crops on cultivated land.

The introduction of more efficient milk production into developing countries in the tropics and subtropics raises a number of environmental issues in relation to human, plant and animal ecology. The terms, tropics and subtropics, are used in a general way to include many types of eco- and agro-climates—countries in equatorial latitudes, the wet and dry tropics with variable lengths of dry season, the monsoonal lands of

Pakistan, India and south-east Asia, the winter-rainfall regions of North Africa and the Near East with cool winters and hot, dry, subtropical summers, the intensity of all these being ameliorated by altitude We are concerned, using herbage criteria, with the lands in which the clovers, particularly white, red and subterranean clover (*Trifolium repens*, *T pratense* and *T subterraneum*) and lucerne (*Medicago sativa*) do not make a major contribution to the grazing and fodder resources under dry-land conditions

Milk is the end product of a particular type of relation or series of interactions between soils, climate, plants, animals and human beings We have to deal with the soil, its nature and fertility, the availability of surface and underground water resources to supplement the rainfall and to make year-round production of fodder for milk possible, the nature of the aerial environments in general or specific terms, the adaptability within these environments of a variety of fodder and grazing plants, and finally the types of animals especially suitable for the purpose due to their potential productivity and adaptation to environment, and their ability efficiently to convert feeds, fodders and grazing resources into the final product, milk Although it is recognized that sheep and goat milks do, in certain countries, make a major contribution to human nutrition, this review is limited to bovines, since it is with these that dairy development in the present context is primarily concerned

Milk production from bovines as an efficient and profitable industry belongs primarily to the humid temperate latitudes, but it is now being introduced, one might say forced, into environments for which this type of animal husbandry and its associated fodder production are not always well adapted Great efforts have to be made to overcome the limitations imposed by these adverse environments, largely by changing traditional standards of animal feeding, management and disease control The management of dairy cattle by farm workers in the tropics requires a higher level of knowledge and experience than is to be found or is necessary among similar workers in temperate areas, yet too often the work is left to those with the lowest levels of education and training There are those who argue that dairy farming is likely to be most efficient and economic when it is practised in the most intensive way possible, and those who hold different views

It is not possible to consider milk production in the tropics in ecological isolation Much of the concentrate feed used by dairy farmers in temperate climates comes from tropical and subtropical latitudes, the more dairy farming is developed in the tropics, the less of these commo-

dities will be available for the temperate zones, which will then have to depend more upon high standards of pasture management and fodder conservation. On the other hand, if it should become clear that dairy farming in the tropics is not feasible either technically or economically, we must consider whether milk production in the favourable temperate latitudes could be increased sufficiently to meet the nutritional demands of the inhabitants of the tropics.

Definition of Targets

There would appear to be some need for clarification, or a more precise definition by the specialists in human nutrition in the tropics, regarding the targets for consumption of milk and milk products. It is essential that those concerned with the planning of milk production should be given a clear idea of their objectives. No standard regarding milk requirements of the entire population has been laid down by an international organization. It is, however, generally accepted in India that the approximate milk requirements of different age groups are as follows:

Age group	*Optimal requirement in ounces per day*
Infants	20 to 30
Pre-school children	16
School children	10
Adults	6
Expectant and nursing mothers	16

These allowances are based upon the nutritional needs of the various age groups and the quantity of milk required to meet the needs of animal protein and calcium in average diets consumed by a large majority of a primarily vegetarian population. On the basis of the above figures, the national requirements per caput will work out regularly to an average of 10 ounces per day, which is the figure suggested in 1944 by the Nutrition Advisory Committee of the Indian Council of Medical Research. It is this figure which provides the production target of 133 million litres per day (Table 38).

The precise requirement of milk in the Indian diet obviously cannot be considered in isolation but only in relation to the other ingredients in that diet. It is not possible to be precise about milk requirements, but one can speak in terms of figures for requirements of different nutrients

such as protein, vitamins, etc Protein needs may be met through a variety of protein-rich foods of animal and vegetable origin Since animal foods provide proteins of relatively better quality than vegetable foods, it is desirable that a certain proportion of the protein requirements should be derived from animal sources

Although Indian specialists in human nutrition still retain the theoretical target of 10 ounces per head per day, they realize that the rate of increase of milk production in the country is necessarily slow, and that even an intake of 10 ounces per head per day may not be practicable within the foreseeable future It has been found that a judicious mixture of vegetable protein foods may supply proteins of fair quality in the Indian diet It has, therefore, been felt that, provided a mixture of such vegetable proteins is assured in the diet, the level of milk intake could be reduced to a figure of 6 ounces per head per day It is this figure which provides the production target of 80 million litres per day (Table 38)

It would be well if those responsible for promoting milk production and processing in the developing countries should be fully aware of the magnitude of the task upon which they have embarked Most of the major milk-producing countries of the world are in Europe (including the U S S R), North America and Oceania In 1963–4, these countries produced 450 million litres of milk per day (Table 1) for a population (1965) of 900 million This amount of milk was produced from about 65,000,000 cows with an average production per lactation of about 3,200 litres (It is not known whether the figure for number of dairy cows refers to total bovine population, or animals of breedable age in milk or dry, or animals in milk.) The population of the countries of Asia, Africa and Latin America (1965) is about 2,200 million, and milk production negligible in proportion To meet the nutritional needs of these latter countries at the same level, namely 0 50 litre of milk and milk products per head per day, it would be necessary to provide 1,100 million litres per day This would mean the development of a dairy industry in the tropics and subtropics with about three times the present producing capacity of the temperate countries For this production it would be necessary to have 1,100 million productive bovines giving 2,500 litres per lactation, or 200 million bovines (in milk?) of the average yield per lactation already achieved in the developing countries, or at least 400 million bovines giving average yields per lactation current in the tropics (Table 1) This is in regions where there are few animals of these levels of production Animal breeders will appreciate the magni-

tude of that task in relation to the numbers and quality of the bovine populations of the developing countries at the present time. Alternatively, it would call for up to a fourfold increase in production in the temperate countries, if the needs of the populations in the developing countries are to be wholly or partially met from the temperate regions. Even if the advanced countries were to be called upon to produce dried skim milk to dilute high-fat buffalo milk down to 3 per cent or 1·5 per cent fat milk, the potential demand would be very great.

TABLE 1

Production and utilization of milk in developed countries (from Annual Reports of New Zealand Dairy Production and Marketing Board)

Country	Year	Number of dairy cows (in thousands)	Yield per cow (litres)	Total milk production per annum (million litres)	Percentage manufactured
Australia	1964	3,296	2,047	6,723	77·7
Belgium	1963	1,041	3,667	3,825	67·5
Canada	1963	2,915	—	7,542	59·4
Denmark	1964	1,370	3,663	5,017	79·6
France	1963	10,715	2,502	25,285	57·8
Irish Republic	1963	1,482	—	2,628	62·4
Italy	1963	4,935	—	9,153	44·4
Japan	1964	1,238	—	2,929	38·9
Netherlands	1963	1,750	3,942	6,763	71·6
New Zealand	1964–5	2,068*			
		3,128†	2,925	5,755	89·2
Sweden	1963	1,235	3,195	3,780	68·0
United Kingdom	1963	5,004	3,528	10,746	31·0
U.S.A.	1964	18,073	3,433	56,970	50·5
West Germany	1964	5,799	3,442	20,074	63·5
Total		64,981	(av.) 3,234		
Million litres per year				167,190	
Million litres per day				458	

* Dairy cows in milk.
† Total dairy stock (breeding bulls, cows and heifers 2 years and over, and heifers aged 1 and under 2 years, and under 1 year of age).

In either case it is important to know the rate per year at which the total number of productive milch animals may be expected to increase. This figure must differ widely in relation to the quality of the existing bovine population, the possibility of herd improvement, average date

of first calving and duration of interval between calvings, possibility of culling by slaughter, and the availability of adequate feed and fodder resources Under favourable conditions, as in Japan, the number of mature milkable cows in a closed population (no importation of females) may be expected to increase at the rate of about 18 per cent per annum

Assuming that the production of milk is technically and economically feasible in tropical and subtropical latitudes, it will nevertheless be most difficult to establish an industry (and particularly to provide the number of productive bovines required) before 1980 at the earliest By that time, the population of the advanced countries will have increased to 1,023 million, and therefore the demand for milk and milk products by 10 per cent The population of the developing countries in Asia, Africa and Latin America will by the same date have increased to 2,850 million (family planning cannot be expected to have had any great effect by 1980), and by 2050 A D (85 years hence) to 8,000 million[183] in the absence of an appreciable acceptance of family planning We may, however, hope that other countries in Asia may emulate the achievement of Hong Kong, where the birth-rate has fallen steadily during the period 1960–5 from 160 to 130 babies to every 1,000 potential mothers

Of all the factors that operate in the tropics and subtropics to limit the possibility of success with dairy development, this enormous increase in human population is undoubtedly the most important It is quite impossible to ensure now that all the inhabitants of developing countries will receive their nutritionally desirable daily ration of milk and milk products All that the dairy industry in the tropics can now achieve is the provision of a small amount of expensive, locally produced milk and milk products for a favoured section of the community It may be possible to establish an economic and efficient form of dairy husbandry based upon the integration of crop and animal production in a limited number of areas But this can be only a token development, completely inadequate for present demands, let alone a fourfold increase in population in the next eighty five years, and an even more ominous theoretical prospect in the centuries immediately following A D 2050 If the world can complete Stage 1 by increased production and better distribution of crops, for direct human consumption, at the same time restricting population growth, it may be possible for vast numbers of people to cross the threshold into Stage 2 Well-planned developments in animal breeding and husbandry and grassland management, and in the production of feeds and fodders would become important Greater availability of Stage 2 foods would reduce the demand for those of Stage 1

The task facing planners in the Far East, for example, is enormous, as will be seen from a recent report by an FAO/WHO Expert Group on Protein Requirements (1965). The Far Eastern countries have available 6 to 17 grm. of animal protein per head per day. These generalized figures must be accepted with caution, however. A figure of 5 grm. of protein from milk and milk products in India is based upon a hypothetical total national production of milk which is not confirmed by calculations of actual production. For comparison, the amounts of animal protein available in grm. per head per day in other regions were given as: Europe, 20 (Spain) to 57 (Ireland); North America 63 (Canada) and 65 (U.S.A.); Latin America 12 (Peru) to 57 (Argentina); Africa and Near East 10 (Libya) to 33 (Israel); Australia 61; New Zealand 72.

If this faraway goal of balanced human nutrition could be achieved, any reduction in birth-rates due to family planning would again be lost. The major ecological factors of natural selection which have so far eliminated the weaker infants, chronic malnutrition and malaria, would no longer be operative. Populations would probably increase again at an excessive rate, and the demand for food for Stage 1 would again become the dominant factor. An important contribution to population explosion is made by better nutrition in Stage 2, the effect of which has not yet made itself felt in India, Pakistan, China and many other countries.

Against this background of the factors of human reproduction and ecology, it is perhaps a little academic to discuss the problems of plant and animal ecology in their relation to dairy development in the tropics. Yet much more attention must be given to these factors in the planning of dairy development to the extent to which it is feasible. It has been shown that the lactation yield and efficiency of feed conversion of the bovines are the dominant factors. Although fodder production and the provision of grazing on sown or planted pastures are based on a remarkably narrow range of legumes and grasses, it is probably true to say that there are species available that are adapted to most conditions in which dairy development is seriously contemplated. Most of them are, however, quite unimproved and only one stage removed from their wild counterparts, if that. There is need for an intensive programme of plant exploration, collection and exchange in order to broaden the ecotypical and genotypical basis upon which plant selectors and breeders may work. Then the cultivated fodder component of the new farming systems designed to promote dairy development will become available to farmers according to their needs and economic capacities.

Politics of Nutrition

Many of the tropical countries discussed here have political systems based on at least a theoretical equality of opportunity, education and present or ultimate standards of living It is, however, becoming increasingly clear that equal standards of nutrition for all sections of a community cannot be achieved in the foreseeable future It is physically impossible with current knowledge and techniques to provide to the populations of Pakistan, India and south-east Asia enough animal proteins in the form of milk, eggs and meat in amounts per head of population which will have any significance It is nevertheless highly desirable that everything should be done to increase the production of these ingredients of the human diet to the maximum Those urban and industrial sections of the community with the high purchasing power will be able to afford them, thus the pressure of their increased demand and purchasing power will be taken off the food grains and these will remain within the purchasing capacity of the poorer people Socialist nutrition is therefore not at present possible in a socialist state, unless increase in total population makes it impossible to keep livestock and everyone is reduced to a cereal/vegetable diet at the present experienced by the majority

The Production Phases

If after this introduction to the enormity of the task facing the officers concerned with the development of a dairy industry in developing countries, particularly in the tropics and subtropics, courage has not failed, we may proceed to the consideration of the many factors of the natural and induced environment which have to be reviewed during the planning stages Let us assume that it has been decided to establish a milk processing factory, on the basis of a survey of urban demand and nutritional standards and that figures, in litres per day, have been fixed for the initial and later levels of input of milk into that factory Let us also assume that those phases of a dairy project relating to such matters as improvement of access in rural areas, collection, chilling, processing, marketing and distribution are all being taken care of by others This leaves us with those parts of the whole process, the production phases, that are too often seriously neglected, or considered too late in relation to the date of entry into operation of the milk factory

Chapter II

GEOGRAPHY OF DAIRY DEVELOPMENT

Ecological and Other Considerations

Decisions regarding the geographical basis for rural milk production are the responsibility of the specialists in the ecology of dairy production, of the economists concerned with investment, returns and markets, and perhaps above all of the dairy technologists.

The radial limits of production are governed by the interval that may be allowed to elapse in the tropics, with their combination of high day temperatures and unhygienic methods of milk production, between milking and chilling. This is usually said to be a maximum of three to four hours, a radius which, according to the method and speed of transport, seriously limits the potential for milk production in areas remote from markets and with inadequate transport facilities.

The planner of new systems of land use and farming for milk production in developing countries may have to reconcile two contrasting situations. On the one hand, in many areas in which development is planned, the present agrarian structure and pattern of land use and tenure may impose considerable difficulties in the production phases. On the other hand, dairy development offers a way out of an impasse, away from age-old static and sterile systems of monoculture, badly designed rotations, and miserable standards of livestock husbandry. The land-use planner and developer who would introduce dairy farming into a proposed milk procurement area must assess the present position and the limiting factors on the lines indicated in Chapter XIII and decide whether the situation is favourable or could be made favourable for a new and dynamic approach.

The economic viability of an intensive dairy industry depends in the final analysis upon the availability of high-quality feeds and fodders, fresh or conserved, for as many months of the year as possible, to provide a uniform level of nutrition to animals with a lactation yield that will make the cultivated fodder area competitive with the food and cash

crops in terms of cash return per unit area There are only limited areas in the tropics and subtropics where the provision of fodder for sustained and intensive dairy production throughout the year does not depend upon the availability of water for at least seasonal irrigation This commodity is rarely cheap Only an efficient and highly productive dairy industry can be competitive with food and cash crops for expensive water and land It may be that the irrigated cultivation of fodder legumes and grasses needed to reduce dependence upon concentrates cannot be recommended as an economic proposition until the milk yield of the animals per annum or per lactation has reached a certain level On the other hand, farmers who can afford irrigation and the expense of cultivating irrigated crops can surely also afford to buy the better animals that are needed

However, most tropical regions have not by any means reached this stage of refinement Dairy animals of relatively low productivity still have to obtain most of their feed from natural grazing, on which they can produce little milk, and from crop residues and concentrates This low standard of production will be maintained until the economic stimulus of a regular and profitable milk market leads to intensification, based upon improved animals, a maximum of cultivated fodder fed green or in a conserved state, and the necessary concentrate supplement still required over and above that Until then, climate limits the growing season and there is not much room to manœuvre in improving fodder production, yields from annual rainfed fodder crops may be too low to be economic Non irrigated fodder crops and the seasonal growth of natural pastures follow the growth cycle of the locality in question, the nature of this cycle governs the choice between annual and perennial species, between extensive and intensive cropping systems, and between alternative methods of fodder conservation, and so defines the types of animal husbandry that may be practised

Agroclimatic Gradients and Land Use

An agroclimatic or humidity or rainfall gradient may be expressed as follows

(a) In zones with a low rainfall which varies widely between seasons and is distributed in an erratic geographical manner, migratory grazing is practised, since the areas to be covered in search of grazing are so vast and the seasonal location of the grazing so variable geographically that ranching within a prescribed area is impossible Livestock show marked

seasonal fluctuation in condition and number and suffer severe losses in extreme years.

(*b*) Where rainfall is sufficiently reliable in annual amount and geographical distribution, but there are still long dry seasons, it is feasible to keep animals on a ranching system within prescribed limits of land. Livestock show marked seasonal fluctuation in condition unless conserved fodder or concentrates are fed.

(*c*) With further increase in rainfall and shortening of the dry season, ranching units which incorporate a small proportion of good land for cultivation of annual fodders become possible, thus eliminating the loss of weight and condition in livestock characteristic of the first two zones; calving intervals are also reduced.

(*d*) The next stage permits a progressive increase in the fodder acreage in relation to the uncultivated grazing land, the cultivation of perennial fodders or even the sowing of pastures and the practice of rotation with food and cash crops, but still with a considerable acreage of natural grazing land in the unit. It becomes possible to keep better animals requiring a higher plane of nutrition.

(*e*) Finally there are the most favoured areas where rainfall in one or both of the annual cropping seasons is adequate and reliable or where irrigation facilities are available; in these areas most of the land can be cultivated. Since these zones are usually the most densely populated, holdings are generally small and there is room only for a short-term annual fodder crop in the characteristic monocultural system.

Dairy farming may be expected to be a practical and economic proposition in zones (*d*) and (*e*), extending into the bordering zones for the maintenance of dry animals or the rearing of young stock. It is unfortunately true that attempts have been and are still being made to establish milk projects under the conditions described for zones (*a*), (*b*) and (*c*), and in the absence of water supplies sufficient for irrigation.

Stratification by Altitude

R. H. D. Sandford ([65]) has made a rough generalization regarding the ecological zones of Ethiopia, and the types of land use and animal husbandry which are suitable in each, as follows:

(*a*) *Dry Pastoral Areas:* Rainfall 200 to 450 mm.

Suitable for the rearing of cattle and sheep under extensive free ranging conditions. Low densities and light holding capacities of grazing result in hardy stock, generally free from heavy internal

parasite burdens, which will respond quickly and effectively when moved on to better conditions Conditions too harsh for milk production or finishing for beef Suitable for fine wool sheep where grazing does not contain too many needle and burr grasses such as *Aristida* spp and *Heteropogon contortus*

(*b*) *Semi-Dry, Marginal Cropping Areas* Rainfall 450 to 600 mm. Altitude usually 4,000 to 5,500 feet The best natural grasslands in Ethiopia containing species of *Chloris*, *Cenchrus*, *Cynodon*, *Pennisetum*, *Brachiaria*, *Setaria* and *Bothriochloa*, found in this range Areas suitable for rearing and finishing beef cattle, especially in big units with modern ranching methods

(*c*) *Medium and High Rainfall Crop Farming Areas* Rainfall 600 to over 1,200 mm
Altitude 5,000 to 9,000 feet Suitable for all forms of livestock operation including intensive systems and the use of exotic breeds under skilled management

(*d*) *Highlands* Rainfall 800 to 1,200 mm Altitude over 9,000 feet Many of these areas are in fact under cultivation but yields are poor due to thin soils and low temperatures and, the areas being steep and mountainous, erosion is often severe Reafforestation and sheep farming for mutton and carpet wools would make economic use of these altitudes without soil deterioration Too high in general for cattle

(*e*) *Irrigation Areas* Low altitudes and high temperatures Although at present on a limited scale future irrigation projects are likely to develop The opportunities in these projects for intensive livestock production in conjunction with seasonal use of dry hinterlands should not be overlooked Experimentation in the growing and feeding of irrigated fodder crops required

There are many conditions in which it is possible to consider the degree of investment, intensification of production and nature of cattle industry in relation to geographical factors such as distance from the milk factory and its ancillary chilling and collecting centres In a mountainous country like Japan, the return on the investment involved in land reclamation, soil improvement, and pasture and fodder establishment and maintenance in the valleys must be at least three times what it is at higher elevations In considering the place of different types of cattle husbandry in relation to the dairy and beef industries of Japan, the following stratification has been worked out in relation to altitude, accessibility, and distance from village and milk collecting centres[154]

A similar approach might be adopted around milk factories in other parts of the world, based again on the principle that dairy farming calls for the production of the highest quality fodder on the best soils, and gives a high return on the investment if efficiently operated through productive animals.

(*a*) *High altitudes*

Pasture improvement: Ploughing up, fertilizing, fencing and sowing of a limited area, say one-tenth of the whole area being treated; cattle are admitted to improved area for, say, one week per month for grazing, to obtain a high-protein ration as variety to the normal regime on the natural grassland. Natural grassland would be managed in the usual way to provide grazing and hay, with the hope that trampling and manuring by cattle would begin the reclamation process, to be followed by lime, fertilizer and a seeds mixture.

Livestock: Mature breeding cows and young rearing stock of the indigenous breeds; within this and subsequent strata the possible introduction of follower sheep to clean the pasture.

(*b*) *Medium to high altitudes*

Pasture improvement: Discing of natural vegetation, application of fertilizers, and over-sowing with seeds of adapted strains of grasses and clovers (inoculated); elimination of regenerating natural species and promotion of sown species by controlled, but at first relatively heavy, grazing by mixed livestock, combined with the use of fertilizers. Area to be fenced to permit rotational grazing from the start.

Livestock: Indigenous cattle, combined where possible with sheep. Possibly also dry animals of dairy breeds from lowlands. Ultimately the stratum for the breeding and rearing of young stock of imported beef breeds.

(*c*) *Medium altitudes*

Pasture improvement: Ploughing up of whole area, fencing, application of fertilizers and sowing of seeds mixtures of adapted grasses and clovers. Subdivision into units for correct grazing control, with or without milking sheds or parlours and wintering quarters for the cattle. Facilities for harvesting and storing of hay and silage. Possible ultimate development of some form of crop rotation when pastures are ready to be ploughed up. A seed-potato industry has been suggested as a possible economic proposition at the higher altitudes, and this would

be a good way of cashing in on the residual fertility of the grazed pastures

Livestock Dairy farming co-operatives on the Oita pattern Dry stock farms for dairy breeds Fattening of young indigenous animals for sale direct as beef, or to the Kobe beef-fattening industry Ultimately the stratum at which to fatten imported beef breeds

(*d*) *Foothills*

Pasture improvement Similar to that suggested for medium altitudes, blocks to be improved by co-operative effort by farmers of the plains, or the complete integration of temporary leys into farming units of the type practised by the new settlers Again facilities in the co-operative blocks to be provided for fodder conservation and, to a limited extent only, for the cutting of green feed and its transport to the farms at lower elevations (bad examples of the result of continuous cutting and removal of green feed without return of fertility can be seen in many areas)

Livestock Grazing of dairy cows, if within walking distance of the village, or if facilities are available for field milking, and for the transport of milk down to the collecting centres Grazing of dairy cows on temporary leys in mixed farming enterprises, with stock controlled by tethering or electric fences

(*e*) *Valleys and plains*

Pasture improvement The small size of individual holdings limits the possibilities for sown pastures in paddy rotations The present emphasis probably must remain on cultivated fodder crops or Ladino clover for cutting and feeding to stall fed dairy cattle The increase of the present ceiling would create conditions for ley farming comparable with those already existing in the foothill zone

Livestock Dairy cattle, and the indigenous animals required for draught and for the production of stable manure for the arable land

Pattern based on Concentric Circles

For less mountainous countries in Asia and the Far East in general, and in India in particular, another pattern might be adopted, based on approximately concentric circles ([161] and [162])

Inner Circle Radius of 60 to 80 km. from dairy factory, depending upon transport facilities and number and location of chilling centres around the periphery

Cultivated fodder crops in arable rotations.
Fodder from urban sewage farms.
Producing milch animals, stall-fed.
Pigs and poultry.
Crops and cultivars thereof capable of utilizing high soil fertility.

Middle Circle: Radius 80 to 130 km. from dairy factory. Farmers would become accustomed to standards of feeding for dairy animals, so that they might become milk producers when the radius of the Inner Circle is extended through provision of facilities for milk collection.

Sown or natural pastures and cut fodder.
Dry milch stock and rearing farms.
Seed production farms.
Haymaking industry (high-quality fodder crops) for Inner and Middle Circle.

Outer Circle: Radius 130 km. and beyond.

Sown or natural pastures.
Hay harvesting from natural stands, in forests and similar lands.
Fattening dairy males from Middle Circle or breeding and fattening special beef animals or crossbreds (dependent upon market for beef).

Land Survey and Planning

In the original assessment of potentialities in the areas around a proposed milk factory, it is most important to collect, study and classify all the geographical and other data available regarding the use of the land, systems of tenure, size of the individual holdings, the agrarian structure, the type of ownership of animals, and so forth. When a factory has been established and is in operation, there are a number of administrative, regulatory and legal actions which may be introduced on the basis of the original data. In many cases the introduction of an efficient dairy industry represents quite a revolution in land use and farming systems. There are a number of ways in which the direction and rate of this revolution may be guided and stimulated (see Chapter XIII).

It is to be hoped that the authorities responsible for the land in the area around a milk plant will have made or plan to make a comprehensive survey of land types and capabilities, on which may be based new land policies, and systems incorporating the required degree of dairy farming. These surveys may be of the broad land ecology type adopted by the Division of Land Research and Regional Survey in CSIRO,

Australia, and by Taylor [149] in Nicaragua, or of the agro-ecological and agro-economic types developed in South Africa and Southern Rhodesia, and may lead to the grouping of specialized studies tabulated by Whyte[159] (see Fig 1) The classification of land and the expressions of land use potential which arise from such surveys will clearly indicate where dairy farming can best be developed They will show when fodder crops or artificial pastures, dry or irrigated, may be introduced up to a certain percentage of the total acreage in rotation with the major food and cash crops planned for the region in question In agricultural areas provided with new irrigation facilities it is desirable that an obligation to put a certain percentage of the area under leguminous and other fodder crops should be included in the new leases or other agreements with cultivators

Arising from these considerations comes the need to study the integration between crop and animal (dairy) husbandry, particularly the economic size of the holding on which it is possible to practise these types of husbandry together In so many areas in the tropics and sub-tropics, dairy development in rural areas is hindered by the extreme and increasing competition for limited land resources as between food, cash and fodder crops, between man and livestock The cultivator cannot be expected to devote any considerable part of his tiny acreage to the cultivation of fodder crops unless he can be convinced that the return per unit area will be as much as or more than from his food and cash crops When the incentive of a regular market for milk is provided and cash payments are made as soon as possible after delivery of milk to the collecting centre, there is evidence that high-yielding fodder crops can be made competitive provided the productivity of the dairy animals is up to a critical threshold value

Trials are necessary on pilot farms in dairy development districts to show the effect of growing fodder crops in a mixed farming system upon the productivity of the whole enterprise If one fifth to one-tenth of a holding is placed under a well fertilized fodder crop, and that acreage is moved progressively around the farm, will the total yields of the food and/or cash crops from the reduced acreage be less than, as much as, or more than was obtained before the introduction of the fodder crop, and the full return of animal manure into the farming system, using none for fuel? In designing the geography of dairy development, the planner must also consider the relative merits and limitations of the various systems of bovine husbandry which are discussed in Chapter XI

(A) Integrated survey of environment

Climate | Geology | Geomorphology | Soil | Water | Vegetation | Past and present land-use

(B) Synthesis into land units, types and systems

(C) Breakdown into major land-use classes

Forest land | Grazing land | Cultivated land: Rainfed, Irrigated

(D) Specialist studies related to land-use classes

Forest ecology, survey, inventory | Grassland surveys, ecology, succession, mapping | Intensive soil survey, crop ecology, agronomy

Ecology, adaptability, tolerance of domestic animals

(E) Forest management, preparation of Working Plans | Management trials with different types of livestock | Crop adaptability trials, formulation of farming systems, crop rotations, integration of crop and animal husbandry

Measurement of run-off and soil loss under different plant covers and with different systems of management

(F) Evolution of integrated land-use patterns

FIG. 1. Six phases in the classification and analysis of potential of land [159].

The targets with which the land use planner has to deal in respect of a procurements area around a milk plant of specified daily throughput or input may be expressed as

(a) the total productive bovine population (in milk and dry of breedable age, and growing) that is required to provide a sufficient percentage and number of animals in milk at any one time to produce a given quantity of milk per day,

(b) the total amounts of the locally available or potential green and dry fodders, concentrate feeds and grazing needed to feed this total livestock population at all periods of the year, and

(c) the area of farm or other land needed to produce these feeds, fodders and grazing, taking into consideration the average local standards of farming and the average yields of the fodder or straw crops or the carrying capacity of the grazing land

It is necessary to consider the potentialities for improvement of the soil fertility, the water resources, the fodder plants, and the species in the natural vegetation, and finally the livestock, their productivity, adaptability, possibility of change in feeding and management, improvement of situation regarding diseases and parasites, breeding and introduction of more productive animals Fodder improvement and livestock improvement go hand in hand, if the fodder is improved, better animals are needed to provide an adequate return on the greater investment and costs of production, if the animal is improved, it is necessary to provide a higher plane of nutrition so that it may express its potentialities in a higher milk yield

With these basic data, one can consider and calculate many other factors involved in planning and financing development, within an individual milk scheme, for example

(a) the funds needed to assist the producers in the purchase of better animals,

(b) the capacity of one or more feed mixing plants,

(c) the annual requirements of seeds to maintain the fodder acreage, and the size of seed farms needed to produce that seed (remembering that certain seeds are a by-product of normal farm production),

(d) the amount of fertilizers needed to maintain high yields on the fodder acreage, and

(e) the funds needed for subsidies or loans to cultivators on an acreage basis, or for the provision of the above amounts of seeds and fertilizers free or at concession rates during an initial period

Chapter III

PLANT GROWTH AND ENVIRONMENT

Climate, Soils, Topography

The most important factors of the physical environment are climate in its broad sense, the nature and fertility of the soils (including trace element status), the availability of underground or surface water to supplement the rainfall, and the topography of the land. These factors, combined with those of the economic environment, in which factors introduced by man (roads, bridges, etc.) are included, will jointly govern whether a milk project may be a successful and economic venture.

The regions and countries which are covered in this review, and particularly in Chapter XII, represent a cross-section of the equatorial, tropical, subtropical and adjacent world. The Country Studies and general discussion show how the agroclimatic conditions, and particularly the length and nature of the growing season of plants, define the specific problems that arise in any individual country or region, and govern the type of fodder production and hence the type of animal husbandry that may be developed. There are the countries with the 'Mediterranean' type of climate of winter rainfall/summer drought, the monsoonal and other tropical countries with wide variations in length of dry season, the summer rainfall countries, and the arid and semi-arid countries where continued fodder production is entirely dependent upon irrigation and which are exposed to the dangers of salinity.

In discussing developing countries with special reference to the tropics, one must not be too strict about latitudinal boundaries. There are many high-altitude areas well within the tropics that are temperate or sub-temperate in climate, although with short photoperiods. Conversely, there are areas outside the subtropics which nevertheless have summers with marked subtropical characteristics, for example, southern Italy with its annual alternation between northern European winters and North African summers, Japan with its altern-

ation between Siberian sub-arctic winters and humid subtropical Pacific summers

Although some type of parallelism may be propounded on an agro-climatic basis, as between type of fodder production and type of animal husbandry and hence of dairy development, it is also true that each milk scheme within a country even of reasonably uniform climate may have its own special eco-climatic and agro-economic characteristics and therefore calls for individual analysis of the elements of environment and production

The relations between domestic livestock and types of animal husbandry and the environment are discussed in Chapter IV As far as the provision of animal feed is concerned, it may be said with certain reservations that climatic conditions which permit continuous growth of green herbage (most parts of New Zealand, for example), are well suited for a year-round feeding programme based on a maximum use of pasture grass or green fodder, and so for an efficient milk production based primarily on grazing But in most parts of the non temperate world, the provision of fodder for sustained and intensive dairy production throughout the year necessarily depends upon the availability of water for seasonal irrigation of cultivated land What may be true in a 'grassy' country like New Zealand with a well distributed rainfall and equable temperatures may not be true for a humid tropical environment, for example As air temperatures rise and the problem of heat disposal by the animals becomes more urgent, appetite is often reduced in order to reduce the 'heat increment' arising from digestion In most places, however, climatic conditions impose a limit to plant growth because of the occurrence of a cold and/or dry season The grass is green and growing for only part of each year, and it is no longer possible to feed animals on fresh green herbage grazed on the pasture or cut and carried to the stall Special measures have then to be taken to conserve green herbage during the growing season and/or to purchase grain and concentrates to carry the animals over the season of no plant growth The longer the dormant season, the more conservation is necessary and the greater the cost of the enterprise

Agroclimatic Factors

Climatic variability must always be considered when planning the animal husbandry and the fodder production and utilization of a milk procurement area or an individual farm within that area under non-

irrigated conditions. The main factors to be recorded are the variability of precipitation in dry areas, in both annual figures and seasonal changes from one year to another, and the frequency of abnormally cold autumns and springs which curtail the growing season and entail more stall feeding of conserved fodders. The planning of dairy farming units has to be done on the basis of the expected frequency of these and other untoward events. Data on environmental factors which cannot be changed by man (light, temperature, wind, etc.) will indicate the potential growing season, while data on availability of water from rain or from irrigation will indicate the period and duration of the actual growing season. In non-irrigated low-elevation tropical areas, the actual growing season does not differ much from the rainfall season, and may last from less than one month to the whole year, as temperature is not a limiting factor. In areas where irrigation water is available at all times of the year, the actual growing season is the same as the potential because water is made available when necessary.

The routine meteorological data which may be used to define the environment for the growth and reproduction of plants and animals are monthly average of maximum temperatures, monthly average of minimum temperatures, monthly average rainfall, monthly number of rainy days, average relative humidity or saturation deficit of air at appropriate hours of the day, and evaporation in a twenty-four-hour period. Where the rainfall season and the growth periods of annual crops are short, say four months, it would be desirable to give averages for periods less than a month, but these are seldom reliable owing to large variations about the average, especially in dry areas. Such data as could be collected in the time available are given in the Country Studies in Chapter XII.

Apart from the above, other important parameters to be considered are:

(*a*) duration and intensity of season with temperatures too low for plant growth; risk of early and late frost;

(*b*) duration and intensity of season with very high temperatures, with or without low air humidity, which may affect plant growth and influence animal condition, behaviour and production (periods with maximum temperatures about 35° and 40° C, with hot winds); and

(*c*) distribution, variability and intensity of precipitation; average and and extreme dates of beginning and end of rainfall season; data on evapo-transpiration.

L P Smith of the Meteorological Office, Bracknell, Berkshire, England, has used the meteorological parameter, 'effective transpiration', in a study of the distribution of milk production in England and Wales Effective transpiration is defined as the calculated actual transpiration occurring between April and September when the soil moisture deficit has a maximum of two inches within the root zone The full text of the relevant paper is quoted as an Appendix to this chapter, with the permission of the Meteorological Office

Climatic records for the assessment of the potentialities of a particular milk procurement area may generally be obtained from national meteorological services, or these can be requested to make special studies on the new parameters above When records are not available or are inadequate, it is possible for someone with the correct ecological feel for a habitat to study the phenology of the species in the natural vegetation and of cultivated crops of all kinds and so to appreciate the duration of the growing period and to obtain an order of magnitude of actual production The degree of variability from year to year may be interpreted from data on crop yields and production, animal populations livestock losses from drought and starvation, and the routes and limits of traditional migratory movements

To sum up, it is the growth period of the sown pasture or the fodder crop that governs the type of animal husbandry and dairy production that may be evolved in any particular environment In the long, temperate growing season of New Zealand, a maximum period of grazing on sown pastures of perennial grasses and legumes is possible, little conservation of fodder is necessary and therefore a minimum of silos or sheds for storing hay Winter quarters for the cattle are not necessary Irrigation equipment does not have to be provided At the other extreme, we have the monsoon climate in northern India, where most of the green fodder has to be grown under irrigation and cross bred cattle and buffaloes are kept in the sheds during most of the hot season, under conditions in which a dairyman in the United States of America might provide specially designed sheds with air-conditioning

Agroclimate and Production

In discussing the relation between climate and agricultural production in Uganda, Peter Huxley[83] has stated that 'the study of climate deals with the analysis of seasonal levels of various meteorological factors which influence us through the aerial environment Short term devia

tions from the expected climatic pattern are described as weather. In agriculture, a knowledge of both climate and weather is an essential basis for the adoption of any farming system, and practical farmers all over the world have discovered, by trial and error over long periods of time, patterns of farming suited to their respective climatic areas. In many cases today these farming patterns are no longer economically feasible or socially acceptable and, with the present urgent need for increased agricultural production in the developing countries, there is not time for a leisurely approach to the problem of modifying the systems or finding new ones.

'In assessing new agricultural potentialities one is often concerned with introducing crops or animals which, on the basis of their performance elsewhere, might be considered suitable for the particular climatic pattern experienced in the area of development. However, even when introduction is successfully accomplished, it can be only the start of a detailed programme of research designed to interpret, and ultimately to predict, the effects on productivity of factors such as climate.'

The dependence of crop yield on climatic factors is extremely complex and still poorly understood([155]). Many important tropical and subtropical crops exist in a wide variety of forms or cultivars which together achieve optimal yield over a wide climatic spectrum. Generalized statements about the climatic requirements of any particular crop are of little value([14]). Finally, one must consider the high degree of local climatic variability found within broader, geographical or ecological regions, especially within an area of such diverse topography as East Africa or Japan.

'The broad differences in climate delineate the main types of agriculture within Uganda. The cultivation of perennial crops is based mainly on those areas where rainfall is both adequate and reasonably well distributed throughout the year, i.e. in the southern part of the country around the shores of Lake Victoria, and the higher areas to the west and east. Arable cultivation assumes its greatest importance in the seasonally-arid areas in the Eastern and Northern Regions, whilst the semi-arid or arid areas in Ankole and in the north and north-east are virtually restricted at present to livestock production. There are problems of acute seasonal deficiencies of both pasture and surface drinking water in the latter areas, where efforts are being made to find suitable cash crops to supplement incomes. Within these broad divisions there also exists a good deal of diversity.'([83]) Thus dairy development, which is dependent primarily upon high-protein fodder crops grown on culti-

vated land, would be likely to be most successful in the seasonally arid areas in the Eastern and Northern Regions, provided conservation of fodder was done for the dry periods, and also in the regions where rainfall is adequate throughout the year and the superior perennial grasses and/or legumes could be cultivated

There are various ways in which climate can limit agricultural production through factors such as solar radiation, daylength, rainfall evaporation and humidity, and temperature 'It should be borne in mind that field crops experience constantly changing conditions, in which any particular factor limiting physiological processes may vary from minute to minute Furthermore, the same factor need not be limiting in all similar parts of the plant at the same moment in time Thus, for example, plant water stress caused by inadequate soil moisture or by a high transpiration rate, or by both of these conditions, may be the factor which most often limits growth during a certain period, yet a change in mean night temperature, or an increase in the average solar radiation, could still favourably affect production and yield of dry matter Thus, although there is no doubt that rainfall is a prime factor in determining crop yields in the tropics, nevertheless the influence of the remaining factors of the climatic complex also need to be examined with care '(83) In another discussion on the classification of responses of crop yield to water stress on the basis of physiological considerations, Fischer and Hagan(37) refer to the problem of avoiding water stress during critical stages in plant ontogeny, and conversely, the possibility of using moderate water stress at certain times to improve yield and the efficiency of water usage

Soils

Soils are less rigid than some of the climatic factors, since they can usually be readily adapted to crop needs by appropriate cultivation and application of fertilizers But within a climatic region, the productivity of crops and natural grassland may differ widely in relation to soil type Soil fertility is not the only important factor, soil structure and depth may determine the quantity of moisture that can be stored Thus, soil type may also have an influence on the length of the growing season, there may be a distinction here due to rainfall regime, since workers in the Mediterranean (winter rainfall) environment state that on deep and heavy soils the growing season may be longer than the rainy season,(128) whereas in the summer rainfall environment of Southern Rhodesia, a

light soil may have a 20 to 25 per cent longer growing season than a heavy soil.[27] Loss of fertility and particularly trace elements through leaching may be a very important factor in humid tropical environments. Grasses may grow on mineral-deficient soils and therefore have a masked deficiency which is revealed on feeding to cattle. The true deficiencies of a soil, particularly in trace elements, show up when an attempt is made to cultivate legumes, as the classic work in Southern Australia demonstrated.

Water Use and Balance

In the assessment of agricultural potentialities in relation to meteorological data, or the prediction of farming possibilities from existing long- and short-term information about climate and weather, from the ecological and physiological viewpoint of an agronomist,[14] 'the great hope . . . in tropical Africa lies in the development of the methods for the estimation of water use introduced by H. L. Penman[125, 126] at Rothamsted'. He concluded theoretically, and then demonstrated practically, that transpiration in a field crop is essentially a physical phenomenon similar to evaporation and governed by energy income and air movement; that consequently, given a free supply of water, different farm crops will, over periods as long as a week or a fortnight, transpire similar amounts per unit of land area, provided they are level and cover the ground more or less completely, and that this rate is rather less than, but related to, the evaporation rate from an open water surface. He provided also a means of calculating evaporation rates from simple climatic data, in an equation which is reasonably sound theoretically, and sufficiently empirical to be applicable in practice. . . . The use of Penman's methods, modified by current research, could lead to a map of much of tropical Africa indicating the regions which may be expected to experience favourable periods of different lengths in four years out of five; this would become a primary document in tropical agricultural meteorology. The paucity in some areas of even the simple meteorological data required would often be offset by extrapolation over the large areas of fairly uniform conditions which do so much to simplify our comprehension of the tropical parts of Africa.'

With regard to the characteristic patterns of the soil moisture regimes of different climatic regions, Bunting[14] calculates water balance-sheets in Great Britain, and contrasts that situation with what 'occurs in the seasonally arid tropics, where the profile within root range is dried out

to wilting point at the end of the growing season Consequently the crop season may open with no more than a slender balance, and continues as a running fight between evaporation and transpiration, in which ultimately evaporation gains the upper hand as the rains decline Under wild vegetation, particularly if it is perennial, the balance is particularly critical, since transpiration begins almost as soon as there is any water to transpire, so that there is no time at the start of the season to accumulate a credit balance of water in the profile, as can be done with annual crops Under open woodland with annual grass and herbs on the heavy clays at Tozi the seasonal penetration of moisture does not usually extend below 12 inches, whereas under annual cropping it usually reaches 4 feet, representing up to 10 inches of available water, all within root range Hence a region which is markedly arid for perennial plants may be effectively humid for annual ones The distribution of rain in the earlier part of the season is most important for annual cropping scattered rains on bare soils may do no more than allow precipitation to keep pace with evaporation whereas the same total, in concentrated storms, may allow the accumulation of useful reserves before the crops are sown

'In the wetter tropical forest areas the profile is full throughout most of the year, but because the vegetation is evergreen and has to bear the load of evaporation for twelve months a year, a relatively slight decline in the monthly receipt of rain, or pronounced irregularity in its distribution, may quite easily lead to serious shortages of water This is especially likely if the total rainfall is similar to or not much greater than the total evaporation for the year, which must be at least 60 inches in such areas in these circumstances it is not surprising to find that many of the tree species of the evergreen forest have leathery, sclerophyllous leaves and other alleged adaptations to dry conditions

'In the forest belt, or the wetter parts of the savannah region, the close balance between precipitation and evaporation depends largely on the virtually continuous transpiration of the vegetation If the vegetation is removed, as in large scale clearing, water accumulates rapidly in the profile and both run off (which leads to severe erosion) and leaching are greatly accelerated This will lead suddenly, in flat country, to flooding and swamp conditions in valleys and on the lower slopes of the higher ground, and may create a completely unchangeable hydrographic situation At the same time the leaching and erosion may severely damage the soil Consequently in wet country large scale clearing is often dangerous For such areas a more gradual process of

replacement of uneconomic by economic plants will have to be developed, presumably based in the earlier stages on selective thinning of the lower storeys of the vegetation and the establishment of shade-tolerant or shade-demanding perennial crops. So far as I know this problem has not hitherto been defined clearly, though it has certainly been encountered.([14])

'The quantities of water involved in the moisture balances will depend on soil texture and profile depth, but these factors will not greatly affect the general pattern, except that on sands, the efficiency of water use seems to be higher than on clays. On the sands, losses by run-off are lower than on clays while the lower field capacity of the sands enables a given quantity of water to penetrate to a greater depth than on clays, and so protects more of it against surface evaporation. This was very clearly pointed out by the late Dr. John Smith ([141]) in his work on the distribution of tree species in the Sudan. He summarized his conclusions by saying that a tree species which requires $3x$ inches of rain on clay soils will require only $2x$ inches on the sands.'

Assessment of Water Resources

The supply of water for crop growth is so important in eliminating a major factor in the natural environment for dairy development in most of the countries studied in this publication that it must be given top priority at the planning stage. Fodder produced on irrigated land and fed through good animals can compete in economic return with most food and cash crops, particularly if heavily manured and given fertilizers at a rate of 40 lb. nitrogen after every second cut of a tropical grass such as Guinea or the Napier/bajra hybrid in India([116]). Irrigation water reinforced with cowshed wash or diluted and sedimented sewage can produce fabulous yields of green feed in tropical conditions.

It is essential to assess the water resources in the area around a proposed milk project, with respect to underground and surface water and the possibility of storing seasonal surpluses by the construction of community or farm dams (see also Chapter IV). Large amounts of water are required by an efficient dairy industry, not only for the production of irrigated fodder crops and pastures, but also for stock-watering, the cleaning of utensils, the washing out of cowsheds and general farm purposes. The maximum utilization of water has to be considered in the design and layout of farm buildings, and particularly the cowsheds. These should be located on higher ground so that the cowshed wash may

flow by gravity to a lower area on which is grown a fodder crop capable of responding to the high fertility that is so provided An adequate survey would assess the present resources and the possibilities of development for the dairy industry in competition with other forms of land use in the project area When the total desirable acreage of irrigated fodder crops has been worked out, it will be necessary to decide between the various types of flow and sprinkler irrigation, and then to assess the amount of construction work and types of equipment that are required to utilize the water correctly Estimates should be made of the type and output of pump sets, spraying equipment, etc When the total cattle population is known, the water requirement for purposes other than irrigation should be worked out per head of livestock

APPENDIX TO CHAPTER III

by L P SMITH

Effective Transpiration

If the potential transpiration of grass is calculated by the method due to Dr H L Penman, a parameter entitled 'effective transpiration' can be derived, being the summation of the potential transpirations over the period when the soil moisture deficit over the zone of the grass roots is less than 2 inches

The way this is done is shown in the following example

	April in.	May in.	June in	July in	Aug. in	Sept in
Rainfall	2 2	2 5	2·0	2 8	2·9	2·4
Potential Transpiration	2·05	3 15	3 55	3 60	3·05	1 65
Soil Moisture Deficit	Nil	0 65	2+			
Effective Transpiration	2·05	3 15	3 35	2 8	2·9	1 65

Total 15 9 inches

The soil moisture deficit is presumed to be nil at the end of March, during April the rainfall exceeds the potential transpiration and the deficit remains at nil The contribution towards the effective transpiration is the potential transpiration (2 05) During May the rainfall is less than the potential transpiration by 0 65 in and this amount of moisture is withdrawn from the soil, leaving a soil moisture deficit of this amount, the contribution to the effective transpiration is again the

Changes in Distribution of Milk Production

This can be summarized for the eleven regions of the Milk Marketing Board of England and Wales (Table 2)

TABLE 2

MMB Region	1946 Area Million acres	1946 Milk Percent age	1960 Area Million acres	1960 Milk Percent-age	Milk Ratio 1946	Milk Ratio 1960	Average Effective Transpiration
1 North	3·08	8 87	3·08	9 50	2 9	3 1	15·05
2 North West	3·06	24 80	2 97	21 70	8 1	7 3	15 65
3 East	3 85	6·03	3 92	5 15	1 6	1 3	13 55
4 East Midlands	2 11	6 96	2·09	5 60	3 3	2 7	14 10
5 West Midlands	2 26	8·95	2 28	9·90	4·0	4 3	15 45
6 North Wales	0 96	4·03	0 98	4·46	4 2	4 5	16·10
7 South Wales	1 38	5 59	1·42	7 26	4 1	5 1	16 20
8 South	1 66	6 69	1 67	6 31	4·0	3 8	14 40
9 Mid West	1 81	13 24	1 87	14·09	7 3	7 5	15 55
10 Far West	1 76	6 21	1 78	8 45	3 5	4 7	16 40
11 South East	2 39	8 62	2 39	7 59	3 6	3 2	13 90

The correlation between the average effective transpiration and the milk ratio in 1946 was only 0 48 in 1946, but rose to 0 72 in 1960 This implies that if we accept the meteorological parameter as a valid parameter for grass growth, this natural factor has played an increasing part in determining the preference shown by the farmer towards milk production as a method of farming As other cattle and sheep also consume grass, the 1960 correlation may be regarded as very high indeed

The national regional distribution is thus conforming with the climatic pattern and this is strikingly illustrated by the diagram (Fig 2) showing the changes in milk ratio for individual counties

There were 27 counties in the high effective transpiration range (15 4–16 55), these have an average milk ratio of 5 6, and 18 of them have increased this ratio since 1946 In the intermediate range (14 0–15 4), there were 16 counties, an average milk ratio of 3 5, and only 4 of them showing an increase In the lowest range (below 14 0) there were another 16 counties, an average milk ratio of 1 4, and all have shown decreases in the period [144]

Distribution of Cattle

A further verification of the validity of effective transpiration can be

found by consideration of the distribution of the cattle population of England and Wales. Unlike milk, which has shown a shift towards the more prolific grass areas, the cattle distribution has shown remarkably little change over the period considered, despite a rise in total population.

Figure 3 shows the cattle density in the Milk Marketing Board regions, giving a plot of cattle per 100 acres of farming land against effective transpiration for the year 1960. The interesting feature of this graph is the levelling out of population density at the higher levels, suggesting that in areas of high rainfall, restricting factors come into play.

Soil Factor

The limiting soil moisture deficit of 2 inches chosen in the definition of effective transpiration is likely to be affected by soil type. Better moisture-holding soils will enable grass to prolong full growth at larger deficits than thin soils. An improvement to the meteorological parameter can therefore be effected if this limiting value is adjusted to soil type. This has been done by reference to a land classification map, using limits of 2·5 inches for the best quality grassland reducing to only 1 inch in the poorest type of soil.

New areal averages can now be found by the use of such a map, which not only take this soil factor into account but also produce averages over regions which exclude the rough grazing areas where few cows are likely to be found.

To check the usefulness of these improved figures, areas which were more climatologically homogeneous than the administrative areas of the Milk Marketing Board were used (Table 3).

The correlations between the effective transpiration and the cattle, dairy cow and milk producer densities are 0·93, 0·88 and 0·97 respectively.*

There is a long history of agriculture in England and Wales and the general standard of farming is high on a world scale. Therefore the distribution of grassland farming and the changes taking place therein, based on the individual decisions of over a quarter of a million farmers, can be taken as approximately correct and sound in principle. The meteorological parameter of effective transpiration fits the farming

* L. P. Smith, 'Effective Transpiration—a meteorological parameter for grassland', *Proc. First International Symposium on Ecosystems*. UNESCO. Copenhagen, 1965 (in press).

picture of England and Wales and therefore it may be concluded that it is useful in this context and is relatively accurate

It would be tempting to assume that a similar approach could be used elsewhere, but it is extremely important to stress that before any meteorological formula or method of climatic classification is used outside its area of origin, every effort must be made to test its validity against local data of a reliable nature Without such checks, extrapolation could be misleading The fact that the parameter used here has a degree of logic to support it does, however, suggest that it is a promising method of climate analysis in agroclimatology

TABLE 3

Area	Mean Effective Trans-piration 1945–64	Area of farmland (1 000) acres)	Cattle per 100 acres 1961	Dairy Cows per 100 acres 1963	Milk Producers per 1 000 acres 1954	1964	Percent-age changes in producers
North West	15·28	1782	57	22·1	10·2	7·7	24
South Wales	14·93	1622	43	14·4	10·2	8·2	20
South West	14·87	2579	46	16·8	10·0	7·6	24
North Wales	14·78	985	49	12·9	10·5	7·9	25
West Midlands	13·96	3412	39	12·1	5·9	4·3	28
South	13·76	2005	37	15·1	4·9	3·7	26
North East	13·29	3329	37	7·9	5·6	3·7	34
South East	13·06	1417	30	10·2	4·0	2·7	34
East Midlands	13·05	4320	28	6·4	3·6	2·3	36
East	12·80	2944	18	4·2	2·1	1·1	44

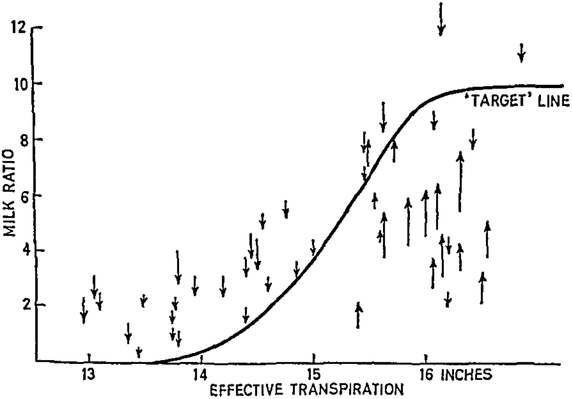


FIG. 2. Change in distribution of milk production in England and Wales, 1946–60 (by counties).

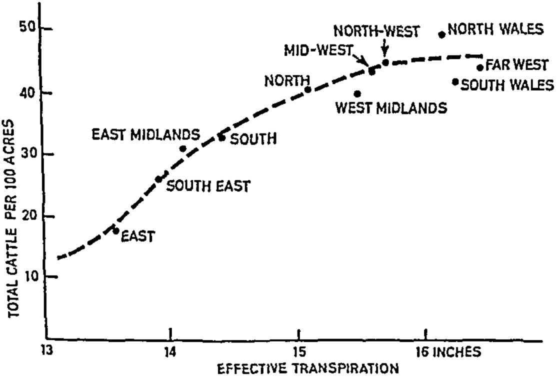


FIG. 3. Density of cattle population in England and Wales in relation to effective transpiration.

Chapter IV

ANIMAL HUSBANDRY AND ENVIRONMENT

The Range of Conditions

The planning of development in animal husbandry has to be based not only upon the environmental reactions of the livestock themselves and the presence of a market for the product, but also and even more so upon the nature of the agroclimate and the extent to which this governs the type of fodder production or grazing regime which may be adopted Insufficient attention is frequently given to the obvious parallelism between the type of animal husbandry, the nature and especially the nutritional or protein level of the fodder which may be produced in a given ecoclimate, and the economic feasibility of maintaining or improving the production of the feeds and fodders in relation to the return and profit from the form of animal husbandry that may be possible under these conditions At one extreme we have, say, the sheep grazing industry of the arid and semi arid lands in India, where sheep giving an annual gross return of Rs 40 (Indian rupee = 1s 6d) may be kept at the rate of one per 3 acres, Rs 13 per acre per annum is not an economic return that gives much room for manœuvre Even if under these difficult ecoclimatic conditions it were possible by grassland improvement to raise the return to Rs 50 per acre, the enterprise is still of doubtful economic value At the other end of the scale, we may have top level dairy farming in temperate agroclimates, with productive animals capable of converting feeds and fodders efficiently and economically into milk

In a study of milk production in developing countries we must necessarily consider bovines kept under a wide range of conditions of husbandry, as described in Chapter XI These conditions range from permanent stall feeding with a uniform plane of nutrition and control of the environment, to free range grazing on semi arid range with maximum exposure to conditions and variations of the environment As examples of the latter system, which seem hardly conducive to maximum

economic production of milk, may be quoted the dairy cattle around the Lake of Chapala in Mexico which spend half the year on the range pastures of the Sierra, and the buffaloes of the migrating cattle-owners, the Maldharis, in Saurashtra, Gujarat, India.

Most milk enterprises in the tropics and subtropics are based upon bovine populations that are very low in productivity and are inefficient converters of feeds and fodders into milk. They cannot be regarded in any way as constituting an efficient dairy industry, nor as a permanent feature of the animal population around a milk factory. Even if it were possible by better feeding and management to increase their milk yield by three times, the total production would still be below the figure at which the cultivation and conservation of high-quality fodder crops become economic propositions. Those responsible for dairy projects must decide whether they will continue to collect the minute quantities of milk produced per animal over an increasing radius to meet the demands of the milk factory, or whether they will by intensification of fodder production and livestock improvement create an efficient dairy industry giving an economic number of litres of milk per annum from each unit area of land and each animal, within an easy radius of the milk factory or chilling centre.

The emphasis should be on improved standards of nutrition and better methods of animal husbandry for the present or a better type of selected improved local breed, rather than on the more ambitious schemes of genetical improvement that have been attempted by cross-breeding programmes or the introduction and maintenance of exotic breeds. These schemes have been adopted frequently with inadequate attention to nutrition and management, and with no thought for the adaptability of the animals to environmental stresses, or for the future of the cross-breeding activities, particularly when the higher grades break down beyond the F_1 or F_2 generation.

Climate and Animal Nutrition

Payne(18) has reviewed the literature on climate and animal nutrition in the tropics, with reference more particularly to Africa and Latin America. The major indirect effect of climate is on the quantity and quality of feed available for the animals. Quality depends mainly on the effective precipitation and humidity and in this respect the humid tropics and the arid tropics present two distinct nutritional problems.

In the humid tropics, the growth of herbage is rapid and heavy yields of green material may be obtained However, quality is usually below that of good herbage from the temperate zone, particularly in respect of dry matter As one of the direct effects of a tropical climate is to depress the appetite, a low dry matter content further reduces the ability of the animal to obtain enough dry matter for maintenance and production The dry matter intake of dairy cattle in Trinidad during the wet season is significantly less than that of the same animals during the dry season [15] The problem is further complicated because the crude fibre content of humid tropical herbage appears to be consistently higher than that of temperate herbage at the same stage of growth[69], an additional disadvantage to animals that are finding difficulty in eating sufficient bulk of watery forage

In the arid tropics there are wide annual variations in the amount and distribution of rain, which are reflected in periods of rapid plant growth separated by long dormant intervals During the period of rapid growth, grasses mature quickly and rapidly reach the stage of flowering and seeding Stock have to graze for most of the year on what is essentially standing hay of very low nutritive value As dry matter content is high, however, grazing animals can obtain sufficient dry matter if an adequate amount of forage is available Since forage is mature over the greater part of the year and conditions stimulate early lignification, the crude fodder content is high and the digestibility of the nitrogen-free extractives is reduced Crude protein content of arid tropical forage is low, being for much of the year around 2 to 4 per cent of the total dry matter, although certain species hold their protein content better than others

Heat Tolerance and Increment

Heat tolerance and loss in animals are closely related to productivity in hot environments Hot weather affects dairy cattle by making it more difficult for them to lose heat from their bodies At air temperatures below 26 5°C , heat can be lost readily by normal processes As air temperatures rise above 26 5°C , heat loss by these processes becomes inadequate and more heat has to be eliminated by a greater evaporation from the lungs involving increased respiratory rates When the temperature of the air reaches or exceeds the body temperature and radiation still acts, all heat must be lost by evaporation It is at these high air temperatures that humidity becomes important, because, as the water

vapour content of the air rises, its capacity to absorb water from the animal's body falls([87]). As air temperatures rise in the humid tropics, for instance, and the problem of heat disposal becomes more urgent, appetite is often reduced in order to reduce the 'heat increment' arising from digestion.

Because ruminant animals depend for their utilization of fibrous feeds on the intermediary activity of rumenal bacteria, there is a considerable development of heat, the 'heat increment', following the ingestion of feeds. This heat increment is proportionally higher for protein-rich as well as high-fibre rations; it imposes an additional heat load on the animal which, in hot environments, must be eliminated. The animal, in fact, has then to balance its nutrient needs against its ability to eliminate the then largely unusable heat generated in rumenal digestion, so as to maintain its body temperature within the physiologically tolerated range. It also shows a greater need for water for the regulation of temperature and for milk production([113]). The ration must therefore be sufficiently concentrated to avoid unnecessary loads of fibre and be readily digestible; as is common in all tropical areas, intakes are reduced to permit a thermal balance to be achieved. This reduction inevitably reduces the nutrient level for milk production because the animal's maintenance needs have first to be met before milk production is possible on a permanent basis. Because of this heat embarrassment, considerable care needs to be devoted to the nutrition and management of dairy animals in hot environments. This has led to revision of housing systems, the use of fans and sprays in the buildings, and to an emphasis on the importance of night grazing.([117, 171]) It has been shown in studies in Fiji, Queensland, Louisiana and Trinidad that European-type cattle kept in the humid tropics and allowed free choice will increase the duration of their night grazing at the expense of daylight grazing. This change in behaviour helps them to reduce their total heat load. Temperate-type cattle that have not been acclimatized drool saliva and mucus and others may lose up to 50 to 80 grm. of minerals per day. The problem of heat dissipation has been examined by Blaxter in *The Energy Metabolism of Ruminants*.([8])

Shacklady([136]) would not wholly agree with the generalization that this heat increment is proportionately higher for protein-rich rations. In cases of sub-optimal or marginal protein intakes associated with a high proportion of roughage of low digestibility, one finds that the general efficiency of utilization of the ration would be increased by some protein supplementation,([16]) see also ([76]). The net effect of in-

creasing the concentration of available nutrients is likely at least to compensate for the heat increment

One may also question whether food intakes are reduced to permit a thermal balance to be achieved or for another reason ([136]) There is a good deal of evidence, much of it from Crampton in Canada, that the voluntary intake of roughages by cows is related directly to their digestibility (see also ([9])). Could this be a factor accounting at least in part for lower food intakes in tropical areas where the digestibility of the roughages tends also to be extremely low? It would be unwise to refrain from improving the quality of the ration with consequent benefit in milk production through a fear of increasing thermal stress Rather one might take the view expressed elsewhere of increasing the concentration of the rations to provide the maximum practical utilizable nutrient intake to compensate for reduced total intake In general, one cannot escape the conclusion that there is perhaps a greater physiological justification for the feeding of concentrates in the tropics than in the temperate zones Yet dairy cattle feeding in the temperate zones is geared to the use of rations of high digestibility whereas in the tropics it is related to a system which aggravates heat stress without being particularly productive

Water Requirements of Bovines

Water is of great importance in the arid tropics, both for plant growth and for the survival of animals, but the effects of deprivation of water on animal productivity have not been extensively studied ([68], [123]) Under normal circumstances heat stress increases the demand for water but as the dry season advances the demand increases still further Restrictive watering reduces the total water intake and apparently also reduces the feed intake at the same time It may also improve digestibility and have other profound physiological effects The decreasing water content of the available forage increases the demand for water at a time when surface water resources are diminishing and the animal has to walk further to obtain both feed and water Additional walking raises the demand for feed and water as increased muscular activity requires additional feed and generates extra heat that has to be dissipated, further depleting the animals' water resources At the same time, ambient day temperatures rise during the dry season with consequent further increase in the water requirements of the animals All these factors combine to subject cattle to very considerable physiological stress

The immediate reaction of cattle to heat stress is to limit feed and increase water intake.[172] This partially explains why the intake of feed by cattle of temperate and tropical types in the tropics is often low by the expected standards of the temperate zones. There are very wide variations within species in the quantity of water used and in the frequency of drinking. Pagot and Delaine [113] have studied the water requirement of *Bos indicus* (Zebu) and *Bos taurus* cattle (with liveweights varying between 246 and 297 kg., and 234 and 250 kg., respectively) maintained under range conditions in the Sudanese zone of Africa south of the Sahara. During the rainy season *B. indicus* and *B. taurus* drink an average of 12·06 and 9·18 litres daily respectively; during the dry season, 21·71 and 19·74 litres; during the transitional season the figures are 24·60 and 21·37, respectively. The moisture content of the forage greatly influences the quantity of water consumed. In both species, water requirements are determined mainly by relative humidity, and when air temperatures approach body temperature, the effect of relative humidity is much greater in *B. indicus* than in *B. taurus*. The latter can therefore tolerate higher relative humidity. This is borne out by the fact that *B. taurus* is the main species in the Guinean zone, which is humid eight months out of twelve, while Zebus are used especially in the Sahelo-Sudanese zone with its nine months of drought. French[68] states that in East Africa *B. indicus* cattle require less water than *B. taurus* breeds when managed in the same environment. In Japan, the water allocation in litres per day for different types of livestock is: dairy cattle 18 to 63, draught and beef cattle 18 to 45, horses 18 to 54, and sheep 0·9 to 2·7.

Animal Breeding

It is not intended to discuss here the relative merits of different methods of genetical improvement, or of indigenous and exotic breeds, or of dual-purpose versus specialized dairy animals, or of the supposed superiority of the buffalo over the cow in the conversion of fibrous feeds. A contrast should be made between the existing situation of inadequate nutrition to meet the production potential and the hopelessness of trying genetic improvement in such circumstances, and the improved situation when a case can be made for raising the genetic potential once the level of nutrition and management permits this. But genetical improvement there must be, since no degree of improvement in feeding or management can raise the level of milk production above

the genetic potential of the animals involved. Everywhere there are examples of badly bred animals being almost literally stuffed with concentrates in a vain attempt to produce milk If it is found that animals fail to respond fairly rapidly to better feeding and more enlightened management, it is a sheer waste of resources to continue operations with them

Animal breeders have not yet decided on the type of bovine best adapted to the conditions in which milk is to be produced in the tropics There are the protagonists of the Zebu or brahman type, but it is difficult with all but a few breeds within this type (Sahiwal, Sindhi and perhaps Tharparkar) to obtain a herd average high enough to make fodder production and the purchase of concentrates economic The European types lack adaptability to heat, particularly under grazing conditions, and resistance to the bovine diseases of the tropics The crossbreds between Zebu and European types combine the qualities of adaptability, resistance to disease, and high yield, but these are of lesser value beyond the F_1 generations, when back-crossing to one or the other parent types becomes necessary More complex programmes of inter-crossing of three or more breeds have been introduced to give a new, true-breeding, high-yielding cow in the F_6 or F_7 generations The buffalo also has its place where high-fat milk is required or where ample supplies of imported skim milk are available for dilution or 'toning', or where the banning of cow slaughter makes the Zebu animal unattractive to farmers because of the permanent encumbrance of the useless males produced from improved dairy-type females in which the dual-purpose characters have been reduced by selection for higher milk production Lord Linlithgow's Royal Commission on Agriculture in India[84] warned against this as long ago as 1928, stating that 'in attempting to secure some milk from the fine types of draught animals still to be found in many parts of India, there is a real danger that the qualities that have in the past recommended them to the cultivator will be lost'

The results of a joint project between Government of India and United Nations Development Programme (Special Fund), with FAO as the Executing Agency, will be awaited with interest The scheme will be in operation for an initial period of five years (1966–71) and will be located at the Central Livestock Research-cum-Breeding Station at Haringhata, West Bengal A foundation herd, constantly maintained at about 1,500, of the highest yielding and best producing indigenous cows will be selected These animals will be inseminated with imported frozen semen from Brown-Swiss, Holstein or Jersey sires The progeny

of these cows will be selected for adaptability, productivity and fertility. The selected cows will then be bred to selected bulls in a carefully planned breeding programme. Records of milk production, growth and health will be kept to determine the grade or combination that is best adapted to local conditions.

Chapter V

ROLE OF NATURAL GRASSLANDS

In the world agricultural literature, the terms 'pasture' and 'grassland' have acquired a somewhat exaggerated aura of sanctity, following the work of Sir George Stapledon and his associates in Great Britain, of Sir Bruce Levy and his fellow workers in New Zealand, and the other pioneers in many parts of the world in the field of grassland management and improvement. 'Experts' coming from those backgrounds are expected to be able to perform miracles with some new wonder plant or system of management in the most inhospitable of environments

It is well to understand clearly that there is a great difference between the temperate world in which they worked, and the tropical world with which we are primarily concerned The improved pastures that may be produced in temperate or sub-temperate latitudes, centred around the key plants, white clover or subterranean clover (*Trifolium repens, T subterraneum*), will provide a maximum amount of feed for grazing or cutting of relatively high protein content suitable for a considerable part of the ration of the dairy cow On the other hand, the crude protein content of natural pastures in the tropics tends to be relatively low, and the crude fibre content rather high, perhaps because of climatic effects, or of soil fertility, or because of the physiological characteristics of the grass species that grow naturally or may be cultivated *Cenchrus ciliaris* and *Cynodon dactylon* have the capacity to retain a relatively high protein content longer into the dry season than their related species in the tropics In Chapter VIII are quoted East African results which show that milk production and normal growth through a wide range of liveweight changes, are limited either by crude protein, if this is lower than about 11 to 14 per cent, or by total digestible nutrients if the crude protein is much higher than this Since few if any natural grass stands in the tropics have anything approaching a constant crude protein content around 12 per cent, the limitations of tropical grasslands and the need for high protein cultivated fodder grasses and legumes become obvious

On the other hand, the crude protein content of a planted pasture grass

like Pangola (*Digitaria decumbens*) in Trinidad may be adequate during the wet season for maintenance and the production of at least 7 litres of milk per day.[15]

The natural grasslands of the tropics (or 'grass covers', since the term 'grassland' is used for one of the physiognomic types of vegetation) include many and varied types of savannah, scrub and other non-forest vegetation, and the grass covers associated with open types of forest. The grass covers of Africa have been described and mapped by Rattray[131], a book on the grass covers of India is in preparation by Whyte, Dabadghao and Shankarnarayan,[163] and FAO is engaged on the compilation of a map of the grass covers of Latin America. The vast grassland areas are frequently stated to represent a great potential, but undeveloped resource for increased production of a wide range of livestock products.[169, 25] Although opinions may differ widely, it is probably true that this assumption is not realistic for the great majority of tropical and subtropical grasslands, at least as far as economic and intensive dairy production is concerned.[158] Certain types of tropical grass associations are of value for beef cattle production on the ranching system, others in the arid and semi-arid zones for sheep and goat grazing. In general, however, the higher forms of animal production, such as dairy husbandry, can only be maintained after ploughing of the original stand, and its replacement by newly sown or planted species.

The question may be considered in two contrasting geographical respects: the residual grassland areas within easy reach of villages or other centres of milk production, and the large expanses of tropical grassland generally located in remote and undeveloped areas. The residual grassland areas, the unimproved village pastures and other types of wasteland in or near areas of human population will continue to provide nutriment of very limited quantity and quality for the low-producing animals that at present supply many milk factories. But the better his dairy animals, the less does the tropical and subtropical farmer rely on natural grazing land to provide anything other than an exercise ground.

On the other hand, the great expanses of natural grassland, subclimaxes in forest climaxes due to fire or other factors, tend frequently to be a snare and a delusion. The species in them are of a poor type which may achieve a digestible crude protein content of no more than 10 per cent for a very short period in their annual growth cycle, and which rapidly becomes fibrous in the dry seasons. These grasslands are

frequently associated with mineral-deficient soil, as in the Rupununi savannahs of British Guiana and other parts of Latin America, or with highly acid soils as over much of Brazil To convert them for dairying would involve a major job of land reclamation which would probably be better directed towards some form of integrated land use with dairy farming as an important part of the overall agricultural pattern

But this is not to say that natural grasslands are of no value as parts of a dynamic form of dairy development. It is necessary to survey the natural grazing lands within a milk procurement area, on the fringes of that area, and in more remote districts, to assess their present botanical and ecological status, to define the degree of deterioration or otherwise, and to advise upon appropriate methods of ecological management or improvement assisted perhaps by cheap methods of surface seeding with superior species In tropical and subtropical latitudes where soil erosion is such a problem, the role of all plant covers, whether natural or artificial, in conserving soil, helping to control the hydrologic cycle, and in reducing desiccation, must be borne in mind in designing systems of controlled or free-range grazing on natural grasslands

But above all, it is necessary to analyse the herbage from natural grasslands for its content of nutrients month by month throughout the year, so that an intelligent programme of animal husbandry and nutrition may be evolved In considering the potentialities of natural tropical grasslands, one must also remember that cattle can harvest a diet superior in quality to that of the forage as a whole with which they are presented, selecting more protein and less fibre ([79]) Thus milk production from a low-quality pasture may be possible if the area available for grazing is sufficiently large to give the cattle scope for their selective grazing A related aspect studied([97]) was whether cattle were able to reduce nitrogen output in the urine when deprived of water and fed on forage of low nitrogen content The behaviour of *Bos taurus* and *B indicus* was compared

It is difficult to visualize that the natural sub-climax grasslands of India, Indonesia, the Philippines or New Guinea, for example, could provide an adequate fodder basis for an efficient dairy industry But they may in some cases represent a second line of defence in a system of management based upon high-quality fodder and concentrates, namely, cut green fodder for a brief period of the year, a low-protein hay which is at least a better roughage than paddy straw, and the possibility of establishing dry-stock grazing farms so that the dry and growing animals may be removed from the milk procurement area, to reduce

the pressure on the limited resources of feeds and fodders in that area. The situation may be more promising in those parts of Latin America where the poor indigenous grasses have been suppressed and replaced by superior African species, *Brachiaria mutica, Panicum maximum, Pennisetum purpureum* and others.

That more may be expected from natural grassland, at least of the type of *Hyparrhenia* veld in Zambia (former Northern Rhodesia), has been demonstrated.([140]) Growth here is dependent upon the seasonal rains; there is a rapid flush about November, but by the end of the rainy season in March the herbage has become tall, stemmy and of low quality. Milk producers usually feed concentrates throughout the natural grazing period from November to March. In an experiment, six Jersey cows were maintained on grassland of the following percentage composition: *Hyparrhenia* spp. (mostly *H. dissoluta*) 42, *Brachiaria brizantha* 20, *Setaria sphacelata* 20, *Heteropogon contortus* 13, others 5. The following treatments were compared:

(1) Intensive grazing: a relatively small area of veld was maintained in a young, leafy, nutritious state by application of nitrogen and frequent topping with the mower;

(2) Extensive grazing: cows allowed a large area in which to graze so that by selective grazing they could harvest as adequate a diet as possible (hopefully without eliminating desirable species);

(3) Supplementary feeding: cows given concentrates to supplement their normal free grazing (2 kg. meal supplement per 5 kg. milk produced—two parts crushed maize to one part of a proprietary high-protein concentrate—16 per cent crude protein and 74 per cent total digestible nutrients—fed twice daily during milking).

It was concluded that milk yields of the order obtained can be maintained independent of the feeding of supplementary concentrates, if the nutritional value of the natural herbage is improved by topping and the application of nitrogenous fertilizers. The fairly high rate of stocking associated with this management will result in higher production of milk per unit area. The alternative system of grazing at a relatively low intensity results in only a slight reduction in milk yields. This is probably better suited to the less developed agricultural techniques of African farmers. In either case, dairying on natural pastures is possible only during the four rainy months when grass grows actively.

It is therefore necessary to know more about the milk-producing potentialities of the grasslands of the tropical and subtropical world, and what can be achieved with slight adjustments in management.

Some grasslands will be of value for the more extensive forms of dairy farming. Others will be more suitable for the secondary roles in intensive systems of dairy farming, such as the maintenance of dry animals, the rearing of young stock, perhaps the fattening of male progeny, and the harvesting of low-protein hay.

Chapter VI

THE FODDER BASIS OF MILK PRODUCTION

The Ideal Objective

Animal husbandry for the production of milk from bovines is, or may be made a most intensive form of animal production, involving an efficiency in the conversion of high-quality nutrients almost comparable with that achieved with pigs and poultry. Dairy development therefore makes great demands upon the fodder agronomist and the plant breeder, who are called upon to provide the very best in edible and nutritive plant material, and to advise upon methods of utilization, supported by manures, fertilizers and water, that will create a basis for the economic production of milk from high-yielding animals.

This, however, is an ideal objective which is far above the present standards of average management and feeding in tropical regions. The milk that is to be produced in most of the projects in the Country Studies discussed here is expected to come, at least during the early stages, from cattle that are free-range grazers on low-quality natural vegetation or scavengers of stubbles and crop residues of varying quality, good, bad and indifferent. When a new market for increased supplies of milk becomes operative, the farmer has first a tendency to buy more concentrates and oil-seeds. It is then that the extension worker and fodder agronomist have to step in and try to find out how and to what extent it is possible to provide cultivated fodders in the green or conserved form, or grazing on improved pastures of adequate yield and quality.

The types of plant materials that may be provided as animal feed, and hence the nature and degree of intensity of the form of animal husbandry, may be considered on the basis of agroclimatic gradients, particularly in tropical latitudes, of the water balance as expressed in the relation between rainfall, evapotranspiration and soil type. When water is available for irrigation, it becomes possible, of course, to overcome the limitations of insufficient humidity in particular seasons or years.

The crops that may then be grown are governed more by temperature and may be chosen for the purpose for which they are required

Cultivars and Seeds

This is no place for a treatise on the adaptability of species and cultivars to the range of ecological conditions covered in this publication Each case must be studied on its merits What will be found remarkable, however, is the small number of herbage and fodder plants that are available to choose from for these varied conditions How many of the hundreds of grass genera have any potential as cultivated fodder or pasture crops or even as useful components in tropical natural grasslands? Plant exploration and introduction for the discovery of new types of economic value must continue,(164) but the greater advances may be expected to derive from the work of the plant breeder Most of the fodder grasses and legumes of the tropical and subtropical zones are merely the result of multiplication and simple selection of wild types, and crop improvement for better growth habit, season of growth and maturity, adaptability to adverse environments and resistance to pests and diseases is essential

It must be assumed that trials have been or will be made to find the most suitable fodder crops to grow, to give the highest return of animal products per unit area The dairy agronomist can then carry out an effective programme of fodder and pasture development only if his work is supported by an ample supply of seeds and planting material of the species that are to be recommended In most of the countries in which our specimen projects are located, the production and distribution of improved seeds of all crops have not been developed to the required standards, and it must be accepted that herbage and fodder plants will be among the last to receive attention Fodder development in dairy projects is therefore exposed to wide fluctuations in the availability and price of seed on the general market, if the present haphazard systems of sale and distribution may be flattered by this name

When the required acreage of sown fodder crops and pastures is known, the annual requirements of seeds of the annual and perennial crops that are reproduced by seed can be calculated as well as the number of slips or cuttings of the tropical fodder grasses which are reproduced vegetatively Steps may then be taken to ensure that these seeds and planting materials are available from a reliable source year after year at a reasonable price When the climatic conditions within or

adjacent to the project area are suitable for the production of seed of some of the crops required, arrangements may be made with the agricultural authorities for the inclusion of these crops in the production programme of established seed farms. The organization and promotion of local seed production may create not only a reliable degree of self-sufficiency within the dairy project, but may also reduce the need to import seed and to use foreign exchange, or to depend on unreliable sources within the same country. Seeds of certain crops, for example lucerne and multi-cut berseem, are harvested from one cut in a series of cuts taken for fodder. These seeds would, therefore, be produced to some extent on farmers' fields, in which case instruction in agronomic and harvesting methods have to be provided, and some type of co-operative system of distribution evolved.

Having decided what crops are likely to be adapted to a particular procurement area, we then have to consider their place in the present or revised farming and cropping systems, and how they may be fitted into crop rotations to the benefit of the farmer and his cattle. When this pattern has been worked out between the farmer and the fodder agronomist to their mutual satisfaction, they consult the animal nutrition specialist and jointly evolve a pasture and fodder calendar. This will represent an optimal synthesis between animal requirement and potential availability of green or conserved fodder month by month throughout the year.

Grazing versus Cut-and-Carry

This introduces the perennial discussion of the relative merits of the grazing system *versus* the cut-and-carry system, of taking the animals to the pasture *versus* cutting and carrying the feed to them in the stalls or feeding yards. The arguments generally produced relate to the extra costs and labour involved in cutting the feed and carrying it to the animals, and to the fact that this system breaks the fertility cycle—the movement of plant nutrients from the soil to the plant, to the grazing animal and back to the soil in the form of dung and urine. The first phase of pasture management in Great Britain was based on the belief that, if land were heavily stocked with dairy cows and a great deal of dung and urine was being returned to the soil, all would be well. This did not take account of the considerable amounts of plant nutrients being removed from the cycle in the form of milk. A second phase has now been reached where it is found that, after some years of high ferti-

lizer application, high production and high rate of return of dung and urine from the grazing cattle to the land, the amount of phosphate and potash required annually to maintain the level of fertility and production that has been reached is very much less than has previously been thought—on one particular farm in southern England 25 units of phosphate and 35 units of potash per hectare per year will maintain the balance, in combination with very large amounts of dung and urine Quite a long period of build up of fertility is needed before this condition is reached

The position with regard to the tropical and subtropical pastures and to irrigated pastures in those regions requires much more study before conclusions may be drawn The grazing of highly bred, highly productive dairy cows in the tropics or in the hot summers of the subtropics raises a number of problems relating to heat load Under tropical conditions with a long growing season, extended if necessary by seasonal irrigation with clean water, cowshed wash or sewage, very high yields of palatable tropical grass may be obtained Two factors then arise

(a) There is on average temperate pastures a loss of 40 per cent of the herbage due to trampling and urine poisoning, on tall, high-yielding tropical pastures this percentage may even be higher, when grazed, and the loss of precious feed represented by that percentage may be too great to contemplate, and

(b) There must be a threshold value for yield above which too much of the herbage is rendered unpalatable through the dropping of very large amounts of dung and urine by grazing animals

Thus, the higher the yield from a tropical grass crop, the less can one justify grazing it. Some specialists say that when labour is still available and cheap it is preferable to adopt the cut and-carry system or zero grazing and obtain 100 per cent of the yield, provided arrangements are made for full return of animal fertility back from the cowsheds to the land It would be argued that the 40 per cent loss due to grazing and trampling is worth more than the costs involved in the cut and-carry system. Others would say that the more expensive the labour, the more economic will the cut and-carry system be compared with grazing, as it can be highly mechanized, can assure the effective utilization of all the fodder produced on intensively cultivated land, and will make it possible to obtain a higher return per labour hour than in any other system.

We may quote here an extract from a glimpse into the future of farming techniques in Great Britain 'In future, to minimize management and food energy losses all productive stock will probably be kept indoors

(Breeding stocks may still be reared on the hills in the north and west to ensure health and hardiness.) The temperature and ventilation in buildings will be completely controlled. Minimum cost stock feed rations will be programmed by computer day by day and automatically conveyed to livestock to ensure maximum growth rates for each age group.

'Pastures free from grazing damage will be much more productive. Continuous control of soil chemical balance will ensure optimum herbage production. This herbage will be mechanically harvested and either fed fresh or stored in a state of fermentation. Grass and conserved forage will continue to compete with cereal grains for stock food on an economic basis. Field drainage by underground plastic pipes will deposit water in farm reservoirs to be mixed with farmyard manure. This slurry mixture will be pumped back to the fields in summer to maintain optimum plant growth.'[82]

Protagonists of the grazing system may consider that the choice is more a question of density of human population. What may be true with regard to the cut-and-carry system for densely populated areas and farms of small average size may not apply to the many parts of the humid tropics with relatively low density of population. Here it is still a matter of choice between cultivated fodder crops, well-managed permanent or semi-permanent pasture, and natural grassland. It may be more economic to depend upon improved tropical pastures than on cultivated fodder crops. The foothills between the lowlands and the rain forest are looked upon as the correct place for the development of animal husbandry, rather than the cultivated areas at the lower elevations.

Growth Form of Species

The growth form of the grasses has also to be considered. Pangola grass (*Digitaria decumbens*), Rhodes grass (*Chloris gayana*) and molasses grass (*Melinis minutiflora*) are better suited for grazing (and perhaps combining with a legume) than a bunch grass like *Panicum maximum* or *Pennisetum purpureum* and its hybrids with *P. typhoides*. Further, it is primarily because of the growth habit and rank growth of tropical grasses that it has not yet been possible to evolve satisfactory legume/grass mixed stands on the pattern of temperate pastures.

There is perhaps too great an emphasis on the need to achieve such mixtures of legumes (species of *Glycine*, *Centrosema*, *Desmodium*,

Siratro or *Stylosanthes*) with grasses which will be compatible and therefore necessarily lower in growth habit and total potential yield There may be good reason to combine *Stylosanthes humilis* (*S sundaica*) with the existing *Heteropogon contortus* on beef cattle pastures in Queensland,([137 151]) or *Stylosanthes gracilis* with *Chloris gayana* in Uganda,([81]) or an improved pasture of *Cynodon plectostachyus* and *Centrosema pubescens* in a mixed farming system in place of the bush fallow in southern Nigeria,([108]) where in the humid forest zone moisture is adequate for pasture growth for eight to nine months of the year Presumably these pastures are for the use of beef cattle or for dairy cattle of low to medium productivity Mixtures with *Panicum maximum* and *Brachiaria mutica* are surely less valuable With Para grass in West Bengal, it is advantageous to disc the grass stand at the end of the growing season, and to sow berseem (*Trifolium alexandrinum*) as a winter annual, the Para comes up again refreshed at the beginning of the hot season. Alternatively, one may grow non compatible grasses and legumes in adjacent plots, each with their own type of management

Economy in Concentrates

Directly related to this arument and fundamental to the planning of the feed and fodder basis is the need to arrange for a maximum dependence upon green fodder fed in the fresh or conserved condition and a minimum reliance on purchased concentrate feeds We may refer to the fact that, in Zebu cattle at Bangalore, all the maintenance and the production of the first 4 5 kg of milk may be met by feeding Para grass and other items in the absence of concentrates ([101]) In other countries the figures for production from grass/clover pastures of much higher protein content are also higher (Great Britain, New Zealand, Japan) At the National Dairy Research Institute at Karnal, Punjab, growing dairy animals of 160 kg body weight may be fed entirely on lucerne hay (with salt) costing Rs 1 50 per maund (37 kg) or Rs 0 20 per day per animal Larger animals weighing 180 to 200 kg, and growing at the rate of 1 4 kg per week, are fed per day only 3 6 kg straw (Rs 3 50 to 4·00 per maund) and 8 kg berseem (Rs 0 01 per kg cost of production), in the absence of the berseem it would be necessary to purchase and feed 0 7 kg groundnut cake per day The potential production of milk per day from good European cows on good pasture in Great Britain, the United States of America and Kenya has been noted ([73]) Much more experimentation is needed on this question under tropical

a problem with dense stocking and severely controlled grazing than at lower levels of N Excess of winter grass growth becomes a problem The very high levels of nitrogen do seem, according to experience so far, to be more appropriate to the areas of lower rainfall In the wetter areas of the country, the most economic levels appear to be nearer 300 than 450 units

Every possible method of providing fertility to soil must be promoted to ensure high yields of fodder It may be unrealistic to expect farmers in tropical countries to apply fertilizers to their new fodder crops They should, however, have the merits and economics of the practice demonstrated to them, at Poona, Maharashtra, India, the application of 40 kg nitrogen per hectare to the Napier/finger millet hybrid (*Pennisetum purpureum* x *P typhoides*) after every two cuts is found to be economic Anyone designing a dairy farm or milk colony should ensure that the cowsheds are on the higher ground so that the wash may flow by gravity to fields of Para (*Brachiaria mutica*) or other tropical grass capable of responding to high levels of fertility

With the rising standards of living and public health in developing countries, the installation of sewage systems will make available vast quantities of this valuable commodity The City of Madras, with its still inadequate system, produces 136,000 000 litres per day and uses only 23 million on a grass sewage farm, the rest going out to sea In tropical countries with a year-round growing season (provided supplementary irrigation is available for the dry months), very high yields of green fodder (up to 300 000 kg green per hectare) of great value for dairy animals can be produced with sewage irrigation For the sake of argument it would be desirable to express litres of sewage in terms of litres of milk that may be produced from feeding sewage irrigated grass to dairy animals Any type of waste land may be used for the purpose, even coastal sand, as at Trivandrum, Kerala

The authorities concerned with public health engineering and with dairy development should collaborate to ensure the maximum utilization of sewage, by designing the sewage farm correctly, with oxidation facilities and sedimentation tanks sufficient fresh water for dilution to the desired concentration, good underground drainage, and allowance for disposal or re use of the final effluent The choice of grass may be important, because in due course the level of the beds rises above that of the inlet channels through the constant deposition of solids A bunch grass like *Panicum maximum* is probably better than a spreading grass like *Brachiaria mutica* because it is possible to clean between the plants

and maintain a standard ground level. With Para grass, it is necessary to plough up at intervals, remove the topsoil and plant again at the correct level.

The problem of soil fertility should be considered from the opposite angle also, namely, whether the cultivation of the gramineous and/or leguminous pasture and fodder crops for economic dairy farming has a cumulative effect after a number of rotation cycles upon the overall soil fertility and the yield of other crops in the rotation. Reference is always made in such discussions to the classic experiments at Rothamsted Experimental Station which deny the traditional belief that 'fertile' soils are those rich in organic matter, and that its maintenance is an essential part of good farming. Many of the Rothamsted experiments show that soil fertility as judged by yields of arable crops can be maintained by mineral fertilizers alone, as may be seen from the following summary of the Station Report for 1964:

> For more than 120 years two plots have received only sulphate of ammonia and other minerals, yet they yield as much or more wheat than one that has had 14 tons an acre of dung every year. The ley-arable experiments are much younger—only sixteen years old—but they provide information about more crops and over a wider range of treatments. One is on land ploughed from old pasture at the start of the experiment, another on land that had long carried arable crops. Each has had the same six-course rotation, all-arable crops on some plots while on others three arable crops follow three years in either a lucerne or a grass ley. As the experiment has continued and the manuring has been adjusted in the light of experience, the yields of the test crops have greatly increased; wheat often exceeds 2½ tons, barley 2 tons, and potatoes 14 tons an acre. On both fields the best yields are remarkably similar, in spite of great differences between the amounts of organic material in the soils, and they are as great with the continuous arable cropping as after a three-year ley.
>
> On the old pasture field the organic material is diminishing with all rotations. The fall is much the same with lucerne as with continuous arable, but slightly slower with the grass ley. On the other field the organic matter remains almost constant, but is increasing with the grass ley though not with the lucerne. But wheat yields consistently more after lucerne than after grass. In the all-arable sequence the yield of wheat can be made to equal that after lucerne by giving it enough nitrogen, but this has not yet been achieved after grass. The reasons are obscure, but it is evident that the traditional practice of resting land

from arable cropping by putting it down to a grass ley is not only unnecessary to maintain fertility but can also be less rewarding than other practices

Until it has been possible to obtain results from experiments in developing countries and to draw the necessary conclusions, we may only repeat the argument presented in Chapter I, that the measure of success of a crop rotation or a farming system is not in the potential production of wheat or other cereal from continuous cropping, but in a correct relation between human foods of plant and animal origin The cereal-cum fertilizer school may have to accept lower yields in order to provide the broader base needed for a correct balance in human nutrition, but even this is not by any means proved

Mechanization

Dairy development should be accompanied by an improvement in the standards of farming and so by a greater interest on the part of the farmer in better equipment and more farm machinery This may range from the mouldboard plough, and the cart to introduce animal power for the transport of manure, harvested crops and farmers to market, to the more complex types for fodder harvesting and conservation, and seed harvesting threshing and cleaning The greater utilization of mechanization for the farming operations within the project area should be assessed in a realistic manner, in relation to the present technological level of the farmers Ownership of the more complex types by the State authorities or on a co operative or syndicate basis should be considered Machinery suppliers should be encouraged to conduct trials and demonstrations of new equipment in dairy project areas, so that the specific requirements for each site, crop and type of use may be studied and met

Water Conservation

It is impossible to produce milk without water—not the liquid of suspect origin and composition that is used as an adulterant, but the basic requirements for plant and animal physiology It is believed on the basis of circumstantial evidence that the availability of ample irrigation water, where possible reinforced by cowshed wash or sewage, makes it possible to obtain a higher cash return and profit per hectare from milk produced by good animals than from any other food and cash

crop. This applies primarily to the high-producing African grasses, Guinea (*Panicum maximum*), Napier (*Pennisetum purpureum*), Giant Napier (*Pennisetum purpureum* × *P. typhoides*) and Para (*Brachiaria mutica*) in the long growing season (with supplementary irrigation) of the humid or dry tropics. But let us take an example from a non-tropical environment, where availability of water for pasture growth has long been a serious limiting factor in dairy production.([22])

The University of Sydney's McGarvie Smith Farm at Badgery's Creek near Sydney, Australia (like large areas on the Australian continent and elsewhere at similar latitudes around 35 degrees) has a reasonably high but most erratic rainfall. The average annual rainfall is 29 inches but in the last twenty-six years this range has been from 13 inches to 67 inches. The within-year distribution is no less variable and there is no single month in which adequate rainfall can be reliably recorded. Furthermore, the shallow clay soils of the Badgery's Creek Farm have a surface of low permeability and about 50 per cent of the rainfall, most of which occurs as heavy storms, is usually lost by run-off.

Before research began in 1952 the native pastures would not support dairy cows at all unless the cows were fed high levels of purchased concentrates and roughages, and these native pastures would support only about one dry beast to each 10 acres. However, by constructing earth-walled dams and ring tanks to catch run-off water and by applying this water in the form of sprinkler irrigation to well-fertilized pastures and forage crops when the species composing them are responsive to irrigation, it has been possible to provide high-quality field grazing for Jersey cows during the whole of the year and to produce more than 1,000 gallons of milk per irrigated acre.

The principles governing the development of this scheme have been those of discovering how to impound water cheaply and efficiently; determining how to use this water most efficiently during any month of the year for the purpose of growing high-quality dairy cow forage, and finding out how the feed so produced can be most efficiently converted to milk by means of the grazing cow.

The growth-rate and water use curves produced for one particular environment have been modified for a range of different environments; using these as a base, it is now possible to draw up specific requirements, on a per cow basis, for any particular farm. These requirements include: water storage per cow needed, the acreages of different species needed, the times when they need irrigation and the times and rates of utilization of the various forages by the herd. It has, in fact, been possible to pro-

vide for individual farmers a water storage, irrigation, pasture production and pasture utilization plan which, if rigidly adhered to, will provide a continuous supply of milk at a much lower cost than that possible with hand-feeding The scheme is being applied widely throughout eastern Australia and is already finding application in North America

It has also been possible, by studying the growth patterns of irrigated pasture and fodder species, to define the periods of the year when each combination of species will efficiently use water for the production of high-quality cow forage By a system of planned use of water it has been possible on a farm scale to produce, throughout the whole year, forage for a water cost of less than 800 lb of water per pound of dry-matter in the forage grown With a cow giving an average of 3 gallons per day, eating 30 lb of high-quality forage each day, the water needed per cow per day for cow food is about 24,000 lb or 2,400 gallons To this must be added drinking water and water used in the dairy, not more than 60 gallons per cow per day The total water needed per gallon of milk produced by a 3 gallon (average) cow would therefore be 820 gallons

Measurement of Production

The grassland and fodder agronomist who is engaged in field experimentation or in the planning of farms for increased dairy production often has need of some acceptable measure of the effective fodder output on a particular field or farm The production of a grazing or fodder field has to be calculated from records of grazing and feeding stock and must also take account of any additional feeding they may receive Variables such as the weather, class of stock and treatment of the sward or crop have also to be considered This problem has been studied by the British Grassland Society in collaboration with the Grassland Research Institute and the Milk Marketing Board in England ([26])

'A detailed comparison over a three year period of the two main systems of recording (cow days and U S E *) demonstrated that they gave equally good results, when individual fields within a farm were being compared This made it possible to recommend the cow-day as the most useful unit for recording the output of fields on dairy farms because of the simpler calculation

'The U S E system has some advantages for it takes account of the level of supplementary feeding, but this can also be shown periodically in a farm management efficiency measure and nothing is gained by

* U S.E = Utilized Starch Equivalent

repeating the calculation for each field. Nevertheless, a measure of animal production being achieved from grass is still an essential part of grassland recording and the U.S.E. system offers one way of doing so.

'The intake of grass by animals varies from day to day but neither the U.S.E. nor the cow-day system records these differences. It is, therefore, pertinent to emphasize that recording systems do not offer a precise measurement of output but indicate the general level of production and so enable differences of more than some 10 to 15 per cent to be recorded. The grassland farmer can also obtain similar information about response to varieties, fertilizer applications and other management techniques as does his arable counterpart in other ways.

'Field production is assessed by recording the number of stock belonging to different categories which graze in each field and converting this to the number of cow-days represented by the breed concerned.

'When stock receive bulk feeds other than grass the potential number of cow-days provided by these feeds is deducted from the field total by applying the standards given in Table 4.

TABLE 4

Great Britain. Cow-days per ton of feed[26]

	Friesian Shorthorn	Ayrshire	Guernsey	Jersey
Hay	68	80	97	112
Silage	21	25	30	32
Kale, roots	17	19	22	25

'This gives the picture while the livestock are at grass, but silage and hay taken from fields must be taken into account by adding an estimate of the potential cow-days they provide. . . .

'A study of the intake data shows that breeds may be equated in proportion to liveweight, and cow-days adjusted to standard cow equivalents. One standard cow equivalent represents the amount of feed a 1,000 lb. lactating cow will eat in 24 hours. A conversion factor is calculated by dividing the average liveweight of the recorded herd by 1,000 lb. Examples are given in Table 5.

'The value of field records lies in creating confidence that high levels of production achieved on a few fields can be achieved on others and this offers targets and also standards for comparison.'

Records such as these may reveal facts that are not obvious, such as

that (in England) the range of field output in most farms is 100 to 400 cow-days, that the established grass field may yield 40 to 50 per cent more than a ley re-seeded in the spring, and that the production from Italian ryegrass (*Lolium multiflorum*) is often less than from most long leys even though it may produce more in the first year

TABLE 5

Great Britain Examples of correcting cow days to standard cow equivalents[62]

Breed	Livestock lb	Factor
Jersey	800	0 8
Guernsey	900	0 9
Ayrshire	1,100	1 1
Friesian	1,300	1 3

This is an aspect of grassland and fodder research and development that needs to be considered in relation to tropical and subtropical conditions, where the main sources of nutriment are cut fodder crops, crop residues and concentrates, with grazing on natural or other pastures being the 'supplementary' part of the overall ration It would be highly desirable to be able to assess the relative merits of different cropping and feeding practices under different standards of crop and animal husbandry On the pilot developmental project near Nakashibetsu in Hokkaido, Japan, local officers estimated that one-third of the farmers could be classed at 100 per cent utilization of potential, one-third at 50 per cent, and the remainder between these two limits If in a dairy development project, it is possible to make some such classification in terms of a measure like cow equivalent feeding days, it immediately becomes apparent where the major effort in extension should be directed

Thus, on the basis of all these and many other considerations, the fodder agronomist working in a dairy development project has to calculate how many hectares of the potential fodder crops and pastures, giving the average yields of green and dry matter and/or cow feeding days characteristic of the neighbourhood, are needed to feed the bovine population that is capable of meeting the daily demand of the milk factory This has also to be done for crop residues and concentrates. In many of the countries studied in this publication, straws have to be included in the recommended rations, although they are not good fod-

ders for milk production; wheat straw can have a negative digestibility in a mixed ration, and the limitations of paddy straw are well known. It probably cannot be expected that the cereal acreage will increase greatly and provide more straw as a by-product, but the greater use of nitrogenous fertilizers on cereal food crops will increase the amount of straw available. As regards concentrates, there is severe competition between men and livestock with regard to the cereal grains, and one may in general expect to have in many countries only the by-product such as bran and husks. For these and other concentrates it is necessary to work out the extraction rates and hulling percentages before reaching a figure for the acreage required to provide the much larger amount of concentrates that will be needed if all the dairy development plans in all the countries are to come to fruition. Already in India, which is likely to become a major user of concentrates for dairy production and which is already a major exporter,([165]) the actual area under the crops concerned is falling far behind that calculated as necessary by the Planning Commission, and the yield per unit area is not increasing as expected. In addition, if all the countries that now export the ingredients of concentrate feeds are to retain an increasing proportion to support their own dairy development, a serious situation may well arise (see Chapter VII).

Fodder Conservation

An important problem in the humid tropics is how best to harvest and conserve the surplus herbage that becomes available from pastures and fodder crops which make extremely rapid and vigorous growth in certain seasons in these environments. Reference has been made([169]) to the difficulties of harvesting hay satisfactorily under the conditions of high temperature and humidity normally experienced during the growing season in the tropics, and to the problem of storage of the conserved product without deterioration due to moulding and other causes. In the West Indies and East Africa, tropical fodder grasses such as elephant grass (*Pennisetum purpureum*), Guinea grass (*Panicum maximum*), *Setaria sphacelata* and materials such as sugar-cane tops are being increasingly used for ensilage for feeding during the dry seasons of the humid tropics.([105])

G. Maxwell Davies([24]) notes that there are only very limited areas in the humid tropics where the rainfall is so uniformly distributed throughout the year that supplementation of available grazing resources is unnecessary when farms are stocked to full capacity. There is also a fairly

long period in each year when the growth of pastures and fodder crops is greater than the requirements of the farm animals Unfortunately, even when the best harvesting practices are adopted, the tropical grasses that are best suited to hot humid environments are relatively coarse and of only limited nutritive value Even when nutrient losses in conservation are reduced to a minimum, the final product will be inferior in quality to conserved fodders in the temperate zone The fundamental problem with which agronomists in the humid tropics have to contend is the fact that the surplus herbage which may be harvested for conservation usually grows at a time when weather conditions are quite unfavourable for the making of good hay and/or silage The soil conditions usually preclude the use of tractors and heavy equipment at that time of the year

It is considered that studies of the growth habit of grasses and legumes of the humid tropics are essential, in order to produce varieties which, although perhaps lower in total annual yield, nevertheless give their maximum growth at a season when they may be harvested and made into good hay or silage With the present types, G Maxwell Davies considers that it may well be preferable to delay harvesting of herbage for conservation until a higher incidence of sunshine and the increasing maturity of the herbage will result in an increase both in sugar and dry matter content, even though the quality of the herbage may be lower It should be noted that heavy dressings of nitrogenous fertilizers tend to lower the content of soluble sugars in the grasses

It is undoubtedly true that surface wastage in silage can result in very high losses of nutrients (up to 40 or 50 per cent) where the entry of air is not controlled Satisfactory fermentation and minimal surface loss have been achieved in the Philippines when making silage as easily and cheaply as possible in 'bun'-type stacks The ensiled material is chopped or lacerated, and sufficiently consolidated to avoid high temperatures during and after conservation, The stack is covered with plastic sheets to exclude air and moisture, the sheets being held down by a suitable covering material Even when harvested and conserved during reasonably favourable periods in the rainy season, silage made in pits or stacks with the necessary modification of accepted principles is a satisfactory supplementary feed for high producing dairy cows of European breeds

Chapter VII

CONCENTRATES AND OILSEEDS

The expansion of dairy production in the developing countries will remain for the time being largely dependent upon the availability of oil cakes and other ingredients of concentrate feeds. Unless and until the production of high-quality green fodder on cultivated land is greatly increased, milk producers will tend to feed concentrates for at least part of the maintenance ration and for all the production. The promotion of dairy development on any scale is therefore likely to create a greatly increased demand for the ingredients of concentrate feeds. These will be purchased and fed unmixed according to their seasonal availability on the markets and in the bazaars. The ration will therefore vary widely in quality month by month, and will be fed wastefully to animals of low efficiency of feed conversion. There is a great need for feed mixing plants to ensure economic utilization of resources and optimal nutrition of dairy animals.

An example of intensity of competition for limited resources of concentrates and oilcakes may be given with reference to India, quoted from *The Planning of Milk Production in India.*([168]) The three chief demands for these resources in that country are for working cattle, for the production of milk, and for the poultry industry. The requirements are calculated on the basis of accepted Indian feeding standards (Table 6).

Working cattle: The total net cultivated area is taken as 334m. acres. One pair of bullocks is required to cultivate 10 acres of land. The total number of bullocks required is 66,800,000, disregarding the large number kept for purposes of transport only.

Milk: The milk plants in operation (working at one-third of capacity) or under construction in 1966 have a planned throughput of 3 million litres per day. Milk plants may expect to collect 40 per cent of the milk produced in their own procurement areas; therefore a total production of 7·5 million litres per day is necessary. It is assumed that the average yield per lactation is 500 litres. The calculation refers only to procurement areas around milk plants and not to the milk production of the country as a whole.

Poultry· The figure for concentrates represents the amount needed to achieve the 4th Plan target of 25 eggs per person per year for the whole population, from hens giving 100 eggs per year.

TABLE 6

India Requirements of concentrates for work, milk production and poultry, and resources available ([168])

Type of demand	Requirement (in thousand tons per year)	Resources
Work	40 080	
Milk	8,400	
Poultry	10,125	
Total	58,605	10,000

The concentrate feed position, which is already becoming acute in a number of countries, may be improved to some extent by the following methods

(1) Increase of area of crops providing the ingredients of concentrates—brans are dependent upon an increase in the cereal acreage and a low extraction rate, legume husks upon an increased acreage of grain legumes, cotton-seed upon the cotton acreage, other ingredients upon the availability of land to spare from food and cash crop production,

(2) Improvement in yield per unit area by the provision of better cultivars, plant protection measures and improved agronomic practices;

(3) Provision of facilities for feed mixing, so that rations may be correctly designed and followed in feeding practice, on the basis of standard products of uniform composition and nutritive value, and

(4) The availability of productive animals capable of converting limited quantities of high-protein and other concentrates into milk with the maximum efficiency and heat tolerance

The increased yields and efficiencies of utilization to be expected from the first three measures are limited in extent, and the future availability of some of the ingredients may suffer considerably due to increasingly intense competition with food crops for direct human consumption It is item (4) that can make the greatest contribution to the problem of utilization of concentrates Let us again take the example of India, where the resources available total about 10 million tons per year.

To achieve 80 million litres per day (6 oz. or 0·17 litre per head of human population per day) we need 89,600,000 tons of concentrate ingredients (assuming that sufficient green fodder and crop residues are available to provide a balanced ration) to feed 256 million animals with a lactation yield or herd average of 500 litres.

With lactation yield of 1,000 litres per animal, we need 128 million animals and 51,200,000 tons of concentrates.

With a lactation yield of 2,500 litres per animal, we need 51,200,000 animals and only 33,280,000 tons of concentrate, or one-fifth of the animals and about one-third of the amount of concentrates to produce the same total amount of milk.

Interdependence of Environments

Concentrates are an example of ecological interdependence between temperate and tropical environments. Many of the advanced countries with highly developed and efficient dairy industries depend upon the developing countries for some of their concentrate ingredients. Many of the latter are trying to develop their own dairy industries. If they are successful, less of the locally produced concentrate ingredients will become available for export. India exports about 840,000 tons of oilcakes (mostly de-oiled groundnut) per annum, valued at Rs. 39 crores in 1964–5. This would be equivalent to an indigenous production of 18 million litres of milk per day, if the other concentrate ingredients and green fodders were also available, and the livestock population was sufficient in number and productivity. As these conditions do not exist, the oilcakes may as well be exported to earn the precious foreign exchange. Current shortages and increasing demands are, however, causing a serious increase in the price of concentrates, and hence a reduction in the daily ration fed on the part of the farmers. It can be only a matter of time before the tonnage of oilcakes now exported annually will become progressively and significantly reduced. If this trend becomes evident on any scale in the developing countries, it may be expected to produce compensatory changes in farming and feeding practices in the advanced dairying countries, improved pasture management and attention to maximum quality in conserved feeds such as silage and hay, and perhaps again, even artificially dried green crops for the provision of concentrates.

The situation was reviewed at the Annual Conference of the British Institute of Corn and Agriculture Merchants in April 1965, by Mr.

H C H Graves, who stated that in the late 1930's the world acreage under cereals was 950 million with an average yield of 10 cwt. per acre and a crop of 470 million tons In 1962–3 the area was 1,100 million acres with an average yield of 12 5 cwt and a crop of 690 million tons The figures of average yield masked wide variations between countries For example, in the Netherlands, United Kingdom, Denmark and Belgium in 1963, the figures were over 30 cwt. per acre as against 13 5 in the United States and 11 3 in Canada Yields of rice of more than 30 cwt. per acre were obtained in Spain, the United States and Egypt, over 29 cwt. in Japan and Italy, as compared with 14 3 cwt in China and 7 3 cwt. in India The speaker could see no reason why the average yield might not be raised over the next thirty-five years to at least a 30 cwt. level, given effective educational programmes, sufficiently skilled cultivation, and the use of adequate fertilizers and good quality seeds If this could be done the total world supplies from present acreages would rise to 1,760 million tons

This would give a more than doubled world population a slightly larger ration than either at present or before the last war, but the requirement of coarse grains had to be multiplied by three factors—first, to allow for the increase in population, second, for an increase in calorie standards (Stage 1 of Chapter I), and third, to provide an increasing proportion of the diet from animal sources (Stage 2) On this basis, the requirement of coarse grain would be 1,400 million tons against the present potential of 632 million tons

Great Britain may expect to feel the effect of the increasing demands in other parts of the world, first in the availability of supplies of protein-rich material for animal feed Total protein supplies in the United Kingdom went up from 1,806,000 tons in 1955 to 2,343,000 tons in 1962, and by far the greater part was imported (272,000 tons of fish meal, 21,000 tons of meat meal, 192,000 tons of soybean, 689,000 tons of groundnuts, 128,000 tons of linseed, 101,000 tons of sunflower and 337,000 tons of cotton-seed)

The additional supplies of protein on which Great Britain and other western European countries depend for the maintenance of their animal protein (Stage 2) standards of diet come largely from the regions which, on nutritional grounds, can least afford to part with them. Even though the foreign trade accounts of developing countries would not balance without this export, how quickly might the indigenous populations insist on the diversion of part at least of these exports to the fulfilment of their own nutritional needs? The availability of imported protein in

Great Britain would become less and the terms of this trade would inevitably become less favourable, the more so as industrialization spread. This created the need for more economical production of livestock and feed supplies in Great Britain itself, and intensified research with a view to using the knowledge throughout the world. It was of great importance to Great Britain to double or treble the yields of rice in China or India.

If the average protein content of Great Britain's grain crop of 12·5 million tons could be raised by 2 per cent, the protein gap would immediately be reduced by 500,000 tons. It was sometimes held that fertilizing land to get high grain yields led to reduction in protein percentage. The fertilizer companies might well assist by concentrating on such points. In the meantime, certainly the United States and the Soviet Union should not be content with their present low yields of cereals per unit area. It should be noted, however, that the comparison of average yields is not quite fair. The high yields of western Europe are obtained under an ample, well-distributed rainfall and on fertile soils, whereas the North American figures relate to extensive cultivation in the Great Plains and the Prairie Provinces.

Chapter VIII

ANIMAL NUTRITION AND EFFICIENCY OF CONVERSION

Making the Dairy Industry Competitive

If dairy industries are to be viable they must be competitive in financial return per unit area of cultivated fodder crop with the local cash and food crops This need will be greater when fodder crops are in competition with other crops on irrigated land and perhaps particularly with high-value vegetables and other horticultural crops Those responsible for dairy policy have to decide whether they wish their industry merely to represent a means of converting low-quality feeds, crop residues such as straw, and poor quality grazing into milk through the medium of many low-producing animals capable of subsisting on such a diet When farmers under such conditions begin to feel the effect of a regular milk market, they may obtain the credit for the purchase of better animals, but their higher nutrient requirements are generally met first by the purchase of more concentrates In many countries these are exported for foreign exchange—action may be necessary to retain more for home consumption

Between the soil, the crop and natural vegetation and the environment on the one hand and the milk collecting centre on the other come the dairy livestock, the cows and/or buffaloes which are the converters of the products of photosynthesis into milk In most tropical and subtropical environments they are not efficient converters, due to a combination of poor genetical make-up, low standards of adaptability, and wholly inadequate nutrition and management Tropical animal husbandry requires a high level of knowledge on the part of the personnel concerned In most of the milk projects in these latitudes, the original assessment in terms of livestock potential and requirement has been quite inadequate, due largely to lack of data

If we are to discover the number of milking animals that are required for a proposed milk project and to plan the cattle development policy accordingly, we need ideally to have certain basic data, not all of which

are normally collected by animal husbandry departments and other responsible authorities The results of a survey will provide an essential component of the balance sheet that we are trying to draw up, namely, the total population of cattle and other types of livestock that have to be catered for within the specified radius around a milk factory if the number of producing bovines is to be adequate to maintain the planned daily input of milk, with seasonal fluctuations reduced to a minimum

Efficiency of Conversion

It is necessary also to consider the standards of productivity that are to be obtained in the bovine population In doing so, maximum efficiency of conversion of feeds and fodders must be reconciled with the availability and costs of production and/or purchase of these feeds and fodders Elsewhere it is stated as desirable that maintenance and the first 5 to 10 litres of milk should be obtained from a ration of green fodder and dry feeds in the form of hays or crop residue It will be a matter for calculation and decision whether it is better economically to have a larger herd with a productive capacity around this level, or a smaller herd of higher individual productive capacity, to maintain which it is necessary to feed expensive purchased concentrate feeds which may already be in short supply

Let us take as an example cows in a temperate climate having a body weight of about 450 kg and producing milk of 3 0 to 3 5 per cent butter-fat ([136]) The general approach has been to see how much feed would be required to produce x litres of milk based on an assumed average yield per animal, using the older requirements for milk production which are still generally applicable to low-yielding cows A cow giving 2 litres of milk per day will require

(1) For maintenance 3 15 kg S E * and 0 3 kg D C P †
(2) For production 0 51 kg S E and 0 1 kg D C P
Total for maintenance and production of 2 litres/day
(approx 730 kg p a) 3 66 kg S E and 0 4 kg D C P

Let us assume that a man has six of these cows He will get 12 litres of milk per day for which the theoretical requirement would be 6 × 3 66 = 21 96 kg S E and 6 × 0 4 = 2 4 kg D C P Even allowing for operation of the law of diminishing returns, this is more than adequate for a cow producing 36 litres of milk per day (14 kg S E , 2 5 kg D C P) It

* S E = starch equivalent
† D C.P = digestible crude protein

is unrealistic to suggest that the six 2 litre cows be replaced by one 36 litre cow, but suppose they were replaced by three cows which averaged 9 litres each The requirement for these cows would be a total of 16 2 kg S E and 2 2 D C P per day Thus for a 27 per cent decrease in S E input and a 10 per cent decrease in protein input, the milk output could be more than doubled by half the number of improved cattle Even if the cows gave only 4 5 litres of milk per day the requirement would represent enough food for 4 cows to give 18 litres (17 1 kg S E, 2 1 kg D C P), an increase of 33⅓ per cent in milk output from a population reduced by 33⅓ per cent, with a saving of about 20 per cent in S E and 16 per cent in D C P (see Tables 7 and 8)

TABLE 7

Great Britain Saving in food required to produce 12 litres of milk per day[136]

No of cows	Yield per cow per day, litres	Total yield, litres	Food requirement S E* kg /day	D C.P † kg /day
6	2	12	21·96	2 52
4	3	12	15 66	1 88
3	4	12	12 51	1 56
2	6	12	9 36	1 24
1	12	12	6 21	0 92

* Starch equivalent † Digestible crude protein

TABLE 8

Great Britain Potential milk output by animals with improved genetic characteristics from a quantity of food not exceeding that required to maintain and produce 2 litres of milk per day from 6 cows[136]

Food requirement S.E. kg./day	D C.P kg./day	No of cows	Yield per cow, litres	Total yield, litres
22·00	2 52	6	2	12
11 82	2·02	1	34	34
11 31	1·92	1	32	32
14 46	2 24	2	16	32
17 10	2 46	3	10	30
10·29	1 72	1	28	28
13·44	2·04	2	14	28
9 27	1 52	1	24	24
12·42	1 84	2	12	24
15 57	2 16	3	8	24
18 72	2·48	4	6	24

It is clear that more milk can be produced from fewer but better animals and at less feed cost. What is not so immediately apparent is that these fewer cows should necessitate fewer followers to maintain their numbers, and that the net gain in available food is even greater than would appear from the saving on milk production. Fewer followers would mean more food available for them and the chance of further improvement in their rearing and coming into profit—an ascending rather than a descending spiral. Figures for temperate conditions may not apply to subtropical and tropical conditions because absolute nutrient requirements may differ. But it is still true that the lower the yield, the greater the proportion of the food requirement needed for maintenance. At these low yields, it is undoubtedly more economic to feed one animal to produce x litres of milk than to feed two animals to produce each $\frac{x}{2}$ litres or n animals to produce $\frac{x}{n}$ litres.

The importance of ensuring maximum efficiency of conversion may be expressed in another way, in terms of the number of productive bovines of four different levels of milk production per lactation that are required to maintain a daily production in a District in South India of 150,000 litres per day. It will be seen from Table 9 that far fewer animals

TABLE 9

India. Productive bovine population and amounts and areas of feeds and fodders required to provide 150,000 litres per day, assuming four different levels of average milk yield per lactation, at Coimbatore District, Madras State[170]

Resources	LITRES PER LACTATION 500	1,000	1,500	2,000
Productive bovine population (total)	480,000	240,000	160,000	120,000
In milk	120,000	60,000	40,000	30,000
Breedable animals, dry, above 3 years	120,000	60,000	40,000	30,000
Young stock, followers and others	240,000	120,000	80,000	60,000
Requirements of concentrates (tons)	168,000	96,000	79,992	72,000
Requirements of green fodder (tons)	1,680,000	960,000	679,830	540,000
Requirements of green fodder (acres)	168,000	96,000	67,983	54,000
Requirements of dry fodders (tons)	1,488,000	768,000	519,870	396,000
Requirements of dry fodders (acres)	148,800	76,800	51,987	39,600

are required at the higher levels of production per lactation, and that great economies may be effected in the total amounts of feeds and fodders that have to be provided, and therefore in the acres of land needed to produce them

Livestock and Feed Resources

In relating cattle to feed resources it is essential to know the number of productive animals that have to be fed (in milk, dry and growing), and whether (and how) that number may be brought more into balance with the grazing, fodder and supplemental feed resources It may be necessary to remove all competing types of animals, apart from essential working oxen and perhaps pigs and poultry, from the area around a milk factory, even including arrangements for the temporary removal of dry stock and young animals from the dairy herds There should be regulations and facilities for the removal of all animals that compete for the generally limited grazing and fodder resources, such as any sheep, goats, horses and donkeys that are not essential to overall agricultural production These facilities should also be provided for young surplus bovine males and for discard cows and buffaloes It may be necessary to provide appropriate stock markets at strategic centres Such action will change the proportion of mature productive cows and buffaloes in the total livestock population, and so increase the amount of milk procured from the total fodder and grazing resources within the procurement area The breeding behaviour of the cows and buffaloes has to be studied, particularly the effect of improved nutrition and management on milk yield month by month through the year or lactation, the age at first calving and the intervals between calvings, and the possibility of adjusting calving dates in order to reduce the peaks of milk production

The choice of crops and other items in improved feeding rations is based on the principle that cultivated fodder crops or pastures in the green or conserved form should eliminate the straw and other low-quality roughages to a maximum extent, that they should meet all or most of the maintenance requirements, and that they should if possible provide the first kilogrammes of milk, before it becomes necessary to feed concentrates If this standard of feed and fodder production and utilization can be combined with productive animals, a viable and efficient dairy industry will be achieved In India it is said that one needs to have bovines giving at least 1,000 litres of milk per lactation under vil-

lage conditions (double that on State Farms and Milk Colonies) before fodder production on cultivated land becomes an economic proposition, but the critical point depends, of course, upon the producer price for milk and on other factors. The recent steep rise in the price of concentrates in India without a compensatory increase in price to the producer has caused milk producers to reduce their purchases of these feeds, and so to reduce milk production per animal.

Protein and Energy Requirements

The new rations need not be idealistic, and up to the standards of advanced countries, but they should be realistic. They should provide a basis for progressive improvements in feeding standards parallel with the advances achieved by the agronomist and the farmers. Under more advanced conditions, feeding standards, as well as standards for individual and combined feed components, will need to be re-evaluated if a high-concentrate, low-roughage, early maturing and high feeding programme is practised. According to Glover, Duthie and Dougall([74], [75]), following Glover, Duthie and French([76]) in East Africa, reasonable estimates of the average amounts of total digestible nutrients and gross digestible energy of ruminant feeds can be derived from knowledge of only the crude protein and crude fibre contents of such materials as fed.([30]) These estimates do not appear to be markedly affected, if at all, by differences in class of feed or species of ruminant. Inherent in the relationship is a suggestion that, if a low plane of protein nutrition is prolonged, that is, when the crude protein of the dry diet lies persistently below some 5 per cent in the feed, a common condition on natural grazing lands in the dry season in the tropics, there is likely to be a sharp fall in the total digestibility of the feed.([29])

At the lower levels of nutrition of dairy animals generally associated with grazing in the tropics, the question arises of supplementing the food intake in a manner that is not wasteful. In South Africa, the problem arose of stopping the loss in weight of beef cattle overwintered on the veld where grazing is sparse and very low in protein. The same situation exists in India from January or February until the monsoon breaks in June or July. At Hessarghata near Bangalore, it has been found possible practically to eliminate this loss by feeding hay from an adjacent plot harvested at the correct season, plus about 1 kg. groundnut cake per day to growing male Sindhi animals. In South Africa, a mixture has been devised consisting of urea, maize meal, some linseed or groundnut,

a fermentation by-product (E C Feed) and minerals The theory is that the fermentation by-product promotes the utilization of the relatively indigestible pasture, aided by the supplement of urea and maize Loss in weight is prevented and even some gain may be achieved In trials in South Africa, urea supplementation was given to beef cattle, either sprayed on hay, or compounded into a urea/phosphate block containing 40 per cent urea, 10 per cent molasses, 3 8 per cent P in form of monosodium phosphate, plus traces of copper and cobalt.[23]

Papers[33, 34] on the protein requirements of ruminants in Southern Rhodesia should be considered in a reappraisal of the nutrient needs of indigenous and other breeds in tropical countries, these deal specifically with nitrogen balance trials on the breeds of African cattle receiving diets adequate in energy and low in protein, and the protein requirements for maintenance of three breeds of cattle On high energy diets, the requirement for digestible crude protein is reduced and there is some evidence that this may be due to an increase in digestibility of the protein in a ration of this nature Consequently it cannot be assumed that the protein requirement is only two-thirds of the generally accepted figure Indeed, a protein level of 58 per cent of Brody's recommendation[13] was found to be inadequate in a low-energy ration even though the latter appeared to be adequate in total digestible nutrients, this was perhaps due mainly to the low efficiency with which nitrogen is used by cattle on rations containing inadequate available carbohydrate (see also [97])

Shacklady[136] raises the fundamental problem is it better to attempt to grow more protein for cattle in the form of grass and oilcakes or to grow more cereals? Grass (primarily grass/legume mixtures) and oilcakes will provide the protein but will not, of themselves, produce the optimal ruminal environment for its most efficient utilization Cereals, on the other hand, provide little protein but induce more efficient utilization of what is present Ideally there should be a combination of all three components, but if they are not all available, it is better to have oilcake and cereal or even grass and cereal, but the last thing to abandon would be the cereal Starch depresses butterfat but low fat milk is better than no milk at all One should also mention the possible supply of protein from urea when adequate carbohydrate supplementation is available It is now clear that the efficiency of utilization of protein, and hence the calculated requirement for it, cannot be assumed without regard to

(*a*) the energy level of the complete diet, and

(*b*) the nature of the energy source

A reduction in energy requirement for maintenance might be expected from high milk producers, provided an extreme external heat load is prevented.[151] The feeding of a ration consisting mostly of concentrates and intensively grown roughages of low fibre content raises a number of problems. A careful watch must be kept on milk output and the feed intake should be balanced accordingly. Frequently, one encounters farmers who are using balanced concentrates, but who are feeding them at the same level to all animals so that poor producers are fattened and good producers are sufficiently starved to reduce milk yield. The relevant problems are:

(*a*) the interaction between various feed components which reduces the digestibility of fibrous feeds and thereby interferes with the digestibility of intra-cellular proteins and soluble carbohydrates;

(*b*) the possibility of reducing CH_4 production in the rumen by the correct combination of ingredients and feeding practices;

(*c*) chronic bloat associated with low feed consumption that cannot be alleviated merely by provision of roughage (but possibly due to a high saponin content of the fodders at the stage of growth at which they are fed);

(*d*) under intensive farming with high applications of nitrogenous fertilizers on irrigated fodder crops, the problem of NO_3–NO_2 poisoning and/or the effects of certain feed components probably interferes with animal health and food utilization;

(*e*) with the increasing use of urea for fertilizer and feeding purposes, care must be taken that this substance is not available in a badly distributed form because an excessive intake can seriously disturb metabolism or result in death; the use of urea should also be accompanied by the feeding of adequate quantities of readily available soluble carbohydrates, such as are found in molasses;

(*f*) when under farm conditions an increased consumption of silage is sought, reasons for the rather small intake of dry matter sometimes encountered should be investigated. Again according to Shacklady,[136] there may be a number of reasons for this. Since digestibility of a roughage is a major factor in determining voluntary intake, one would expect the intake of a more digestible silage to be higher than that of the less digestible mature crop (provided that losses of protein and carbohydrate do not so change the composition of the silage that it becomes less digestible). The low dry matter intake could be a function of a high moisture content of the silage and a restricted allowance of time in which

to eat it Secondly, the quality of the silage can affect materially its palatability Thirdly, in the more traditional ways of making silage, there tends to be some considerable wastage as effluent, phosphorus is lost to a greater extent than calcium—perhaps the intake of silage would be increased by the provision of a bone flour/salt mineral lick Finally, there is the mutually beneficial effect of silage and dry roughage offered at about the same time

The utilization of feed energy and probably the total output of energy per unit area in a country such as Israel may be increased by applying the following management practices ([154]) Israel lacks those factors typical of classic milk producing countries, being characterized by absence of permanent pasture suitable for dairy production, shortage of rainfall and water resources, a subtropical climate, and only small areas for cultivating fodder and grain crops

(*a*) Prevention of excessive walking to and from pasture by practising zero grazing, especially for high producing cows in a hot climate

(*b*) Reduction of exposure to sun and heat load by mechanical means, shearing, sprinkling, correct design of farm buildings

(*c*) Provision of all feed intake on an individual or small group basis, roughage and concentrates according to requirements and possibly 10 to 20 per cent above the common standard when feed is cheap and a good return in milk is obtained

(*d*) Chopping of green and dry coarse roughage to enable complete consumption with less energy spent on eating and digestion Chopping is practised in India with all straws, and Government of India gives a 50 per cent subsidy for the purchase of chaff cutters A mixture of green berseem and cereal straw is sometimes made to induce the animals to eat their quota of straw The practice is found to be tedious and expensive in Great Britain and of doubtful value in conserving energy At Beltsville, U S A , the chopping of green material increases the total return per unit area, and is regarded as worth the effort for the control of parasites that is achieved in both cows and calves ([104])

(*e*) Prevention of mechanical wastage and increase in feed value by the use under intensive management of well-balanced and more complete pelleted feeds, fully utilizing the benefits obtained by heating the feeds (more research needed on methods of avoiding consequent reduction in fat percentage)

(*f*) Further action to reduce heat load, possibly utilizing vegetable

or animal fat in the ration (although the additional fat must increase energy intake and much may be excreted undigested).

(*g*) The value of natural versus heated proteins and their appropriate combinations with other ingredients (possibly using non-protein N) need to be re-investigated in the light of recent research, which indicates that ruminants as well as chickens can better utilize roasted soybean and other protein-rich meals (provided the roasting is done under correct supervision and one does not produce 'charcoal').

In sub-paragraph (*c*) above, it is not clear, according to Shacklady(136) whether Volcani might not be adopting the practice, which is being used in Great Britain to some extent, of a kind of dual scale of requirements. Basically what one does is to feed approximately the same amount of concentrate over the whole lactation as the yield justifies, but to distribute it differently from the conventional way. A higher level of feeding is practised in early lactation to take advantage of the 'urge to milk' and the scale is reduced as lactation progresses and yields fall away. It is argued that this tends (*a*) to result in greater milk production, and (*b*) to reduce costs per litre. Jawetz(86) sets out to indicate the profit margin on each litre of milk, beyond a certain stage, in cows of various average lactations, with the object of calculating when the return in extra feeding becomes no longer worth while—the law of diminishing returns illustrated by actual cost figures. Where purchased feeding stuffs are a dominant economic factor, one may conceive of situations where at one moment in time the return in milk production from extra food might be uneconomic, but would become economic again due to a sudden drop in feed prices.

While on the subject of adequacy of nutrition one must be very careful not to assume that, because a cow is producing a certain quantity of milk, the diet is adequate for that level of production. The modern high-yielding dairy cow has such an inherent drive to produce milk that it will do so at almost any cost to itself. If the nutrient intake is inadequate it will not immediately reduce its milk output but will attempt to meet the deficiency from its own body reserves. After this the yield will fall and the animal will ultimately adjust its yield to the lower plane of nutrition. However, the body weight of the cow would have fallen as also would the level of nutrients secreted into the milk. Yield alone—unrelated to changes in body weight and condition and milk composition—is therefore not a good criterion of adequate nutrition.(136) The assessment of nutrient requirements based on higher-yielding cows

demonstrating the buffering effect of body reserves may lead to an underestimate of requirements when applied to an animal with little or no nutrient reserve in its body By its nature the cow can tolerate temporary underfeeding without damage, but it is chronic underfeeding that causes the trouble

Sub-paragraphs (*e*), (*f*) and (*g*) above relate to the whole business of compound feed manufacture with regard to techniques, nutrition, acceptability, economy, etc This is a study in itself and there is ample scope for research and practical trials It is, however, outside the limits of the present review Suffice it to say that a considerable degree of technical competence is required to produce high fat feeds that will pellet satisfactorily Almost as many workers report advantages from pelleting or cubing as the reverse Certainly there are well-established cases where efficiency of utilization is increased by cooking—the object of heating soya is to destroy the trypsin inhibitor that it contains and reduce urease activity The beneficial effect is most apparent with non-ruminants No major damage is done to the protein of a meal pelleted at temperatures of 54°, 71° and 88° C in the presence of moisture and held for the duration normal in this type of processing, vitamins may be affected, but this can be rectified by supplementation With ruminants, the problem is quite different—there are at least two effects to be considered, one being that of processing on butterfat production, and the other on protein utilization With regard to the whole problem of protein in nutrition, the position with respect to ruminants is intriguing and baffling—one may even deduce a requirement for specific amino-acids ([136])

Nutritional and Economic Planning

When we have discovered the total numbers of milking, dry and young stock that are involved in providing the planned input per day of a milk factory, it is possible to present the reasonable feed requirements in terms of dry matter, total digestible organic matter, pounds and percentages of starch equivalent and protein, and other measures adopted by the specialists in animal nutrition Then one has to consider how these requirements may be met under the conditions in question, from grazing of natural or sown pastures, feeding of cultivated fodder crops in the green or conserved forms, of straws and other roughages, and of concentrates For this purpose, it is desirable to have results of studies of chemical composition and nutritive value of the feeds and

fodders grown under the seasonal conditions around each individual milk factory.

The gain or income of a dairy farmer is represented by the difference between input and output from his enterprise. In all countries, feed costs are the greater part of the farm input figures, depending upon the price per unit for production on purchase of feeds, fodders and grazing. The total output is composed of milk produced, animals sold, and the after-effects of manure on fodder and other crops where this is used for soil improvement. All those concerned with the agricultural and animal husbandry aspects of the dairy industry must assist the producer to make the difference between input and output as large as possible, and the best way to do this is to increase the efficiency of feed utilization.([85]) This efficiency has two main aspects, nutritional and economic, and should be related to the whole span of life, covering the large investment that is necessary before the cow is producing up to the time when it has a certain slaughter value. Again we must stress the importance of a good animal and the need for drastic culling and selection for improved strains.

The dairy extension specialist has to keep abreast of the rapid developments occurring at the present time in the field of the nutrition of the dairy animal. This knowledge is needed more particularly in the third phase of the establishment of our milk factory, the period after the factory is in operation and the farmer has an incentive to adopt improved techniques. A fairly extensive system of rearing young stock, ability of cows to calve at regular intervals, a good capacity for milk production, longevity and an early age for first calving are five important criteria for the efficiency of a dairy herd. The system of rearing appears to have an influence on the subsequent intake capacity of the mature animal; in temperate areas some evidence has been obtained to suggest that the less concentrates are fed to the young animals, the more roughages may be consumed subsequently, and also that an intensive rearing system (high amounts of milk and concentrates) has a harmful effect on longevity (data from Great Britain do not confirm this). A less intensive rearing system with early introduction of roughages reduces the cost of rearing and increases the efficiency of feed utilization, provided that the stock are not starved but have a reasonably adequate intake of nutrients to permit skeletal and muscular development.

In most advanced countries the heifers of the dairy or dual purpose breeds calve between 24 and 36 months and milk production starts; the younger the heifer at calving, the more care is needed in its feeding during the first and second lactations. In those countries where feeds

and especially supplements are scarce, the date of the first calving must be later (about 36 to 42 months) because of the body development of the heifer Selection towards higher-yielding animals will mean that fewer need be kept, or that more milk will be produced from the same number In the former eventuality, fewer replacements will be needed and the fodder situation will be eased With more feed available for fewer animals, the plane of nutrition can be raised so that the first calving dates may, it is to be hoped, more nearly approach those obtaining in more advanced countries This in turn means that the animals will be in profit earlier

Production from Grass

The main arguments presented in this publication are that dairy development calls for maximum intensification to achieve economic production, and that this intensification will have a maximum effect on overall productivity of the land if the farmer uses his potential cultivated fodder crops to the maximum in order to reduce his dependence upon purchased concentrates In Great Britain, the agricultural economists claim that there is no evidence of greater milk production from grass and grass products Others would differ from this conclusion, referring to 'so many individual farms where the farmer has achieved the personal break-through of ceasing to rely on concentrates for milk production and of being prepared to let the grass do what it is capable of [15] These latter see a general improvement in this direction and even wonder whether dependence on grass is perhaps not being pushed too far The ability to grow barley continuously on the same land, the very much higher yields now being obtained, and the general reduction in costs of cultivation have all combined to bring the cost of barley down very near to the cost of conserved grass products This could mean that, on land where cereals may be grown just as easily as grass, there is much to be said for reducing the dependence on conserved grass for winter use, and growing instead a proportion of barley for the purpose The barley had the obvious advantage of greater flexibility in use, if a surplus should become available, it can easily be marketed, which is not the case with silage It may well be possible to stock more heavily and to utilize the land more efficiently if there is an area of barley which is not nearly so subject to reduction of yield due to drought One could then take greater risks in the matter of pasture acreage per cow unit

What grass may actually achieve is indicated by the following farm

statement: standard of production in one particular year was a true average (weighted average) for all lactating cows and heifers of 4,377 litres, with a stocking rate of one stock unit to something less than 0·6 hectare of forage crop and a concentrate consumption of about 655 kg. equivalent to 0·15 kg. of concentrate per litre, this in a district with quite serious limitations of rainfall and a relatively long winter.

'Production from grass, for either meat or milk, is a two-stage affair. First, you grow your grass, then you have the job of converting it into the human food product, and no matter how well the first stage of the operation is carried through, the whole thing comes to nothing economically if there is a failure to do the second stage of the job efficiently. Where conserved grass comes into the picture, it represents a third stage, and the loss of nutrients so often involved in conservation may also cause serious economic loss.'([18])

The production of milk from good pasture in England and the United States of America rarely exceeds 16 litres per animal per day, the actual amount depending upon the fat content of the milk and the appetite of the animals. In East Africa([73]) an Ayrshire cow weighing 450 kg. and of average appetite could give at least 14 litres of 4 per cent fat, and a 360 kg. Jersey of average appetite could produce only some 9 litres of milk of 5 per cent fat. According to Glover and Dougall, but not confirmed by French, Todd or Rogerson, the available energy, total digestible nutrients or starch equivalent in the dry matter of Kenya pastures at all stages of growth is remarkably constant. In early stages of pasture growth, the available digestible crude protein is present in amounts suitable for very high milk yields but the available energy is the limiting factor. During later stages of growth, crude protein becomes increasingly diluted by carbohydrate—there is a progressive decrease in the amount of available digestible crude protein, and it in turn becomes inadequate to sustain the original limited level of productivity.

At this point of change-over from T.D.N.* to D.C.P.† as the limiting factor, there is a narrow zone of pasture composition from which maximum production can be obtained with minimum waste. The approximate composition of the pasture of this region can be specified simply by the crude protein content of its dry matter. It is not possible to define the level of digestible crude protein in pasture dry matter that is most efficient in milk production closer than 11 to 14 per cent, until the feeding standards in current use can be more accurately reconciled.

* T.D.N. = total digestible nutrients.
† D.C.P. = digestible crude protein.

Bovine Reproduction and Management

More needs to be known about the reproductive cycles of cows and buffaloes in the tropics, and the possibility of changing them to eliminate seasonal peaks of production, if the programme of fodder production and conservation is to be integrated with the trend of livestock performance and feed requirements throughout the year Buffaloes in particular seem to be closely tied to the season when they come into heat, and so when they calve It is useless to make a great and costly effort to produce or conserve fodder for the months of low productivity when these are known and are reasonably fixed

As already stated, under the less intensive conditions of cattle management common in the tropics and subtropics, it is probably advisable to have a larger number of animals of average productivity and nutrient requirements than a smaller number of animals with a very high production potential and nutrient requirements Where concentrates are becoming scarce and expensive, as is the general picture at the present time, it is better to have more animals which can obtain nutriment for their maintenance and for limited production up to 5 kg of milk per day from farm grown fodders and roughages, and fewer highly bred animals that require large quantities of purchased concentrates to maintain a high level of production Up to the age of about thirty days, most cultivated tropical grasses like *Panicum maximum* can supply sufficient protein for the production of about 10 kg of milk per day, but their energy content limits milk output to not more than about 6 kg per day

Chapter IX

INTENSIFICATION OF AGRICULTURE

Dairy Development as Catalyst

It is possible to recognize two contrasting and yet complementary approaches to dairy development. The one is that of the specialists in human nutrition and dairy technology, with some support from agriculturists, who, when deciding upon the establishment of a dairy project, are concerned only with the provision of adequate amounts of clean milk and milk products for the local population. The other approach is that of the land-use planner and general agriculturist, who should regard dairy farming and dairy development as means to an end, the wide objective being an overall intensification of total crop and animal production from the land. This intensification is assumed to be dependent upon a maximum degree of integration, on the cultivated land itself, of crop and animal husbandry. In such a farming system, fertility-restoring crops may be grown in rotation with fertility-removing crops, and fertilizers may have their maximum effect on the yields of food and cash crops grown on soils rich in organic matter, and not exhausted after decades of monoculture. The improved varieties of cultivars of all crops may on these enriched soils be able to produce up to their new genetic potential. Throughout the tropics the most promising form of animal husbandry for this purpose is obviously dairy farming, provided that the bovines, be they buffaloes, Zebu, or Zebu × European crossbreds, are fed to a sufficient nutritional level on fodder crops grown on cultivated land which is well fertilized and to which all the animal dung and urine are returned.

In developing countries it is essential by every possible means to achieve increases of total production from the land of 200, 300 or even 400 per cent to meet the greatly increased demands for food and other agricultural products that are to be expected in the coming decades. It is postulated for the sake of argument that these large increases may be best achieved by what is usually and rather loosely called intensification of agriculture. This intensification is frequently made the objective of

so-called 'package programmes', involving especially the application of fertilizers, the introduction of improved seeds, the provision of more facilities for irrigation, for plant protection, and for financial credit to producers, and the preparation of modern farm plans for individual cultivators These measures are usually combined with actions directed towards such things as greater rural electrification and the construction of roads and other means of improved access to markets The term, diversification of cropping, is also introduced in a vague sort of way, without indicating whether the objective is a wider range of products for the market, to meet the demands created by higher urban purchasing power and changing nutritional tastes, or the adoption of farming or cropping systems which are better for the soil, or both ([161, 167])

Parallel with, but rarely sufficiently related to these developments, are the improvements in farming practices, based upon a number of premises to which little more than lip service is paid These are referred to in different contexts and at different times as the soil/climate/plant/animal/man ecological relationship, the soil/plant/animal/soil fertility cycle, mixed farming, alternate husbandry involving the regular and controlled rotation of soil-improving with soil-exhausting crops, and the integration of crop and animal husbandry in highly efficient farming systems involving maximum production of plant and animal products, combined with long term conservation of soil *per se*, and of the fertility or productivity of that soil

One may argue that the application of fertilizers to soils exhausted by an age-old system of monoculture, soils that have become poor in structure and low in organic matter, will not achieve the desired results Those who hold this view, and who may be called old fashioned by the other school, believe that it is essential to concentrate first on an appropriate branch of animal production Dairy farming in the tropics is the particular type of animal husbandry which may be regarded as a catalytic force, starting a chain reaction towards real intensification of agriculture and maximum production per unit area of all the foods and other items of plant and animal origin required by a population which is rapidly increasing in numbers and which is changing its demands for food and other products along with general economic progress and increased purchasing power It is believed that the maximum response to fertilizers may be obtained in farming systems based upon full integration of crop and animal (dairy) husbandry This is a question that calls for review in relation to the retention of organic matter, nitrogen and other soil nutrients under wet and dry conditions in the tropics

The above views are based upon the thesis that true and maximum intensification leading to a well-balanced production of foods of plant and animal origin plus cash crops cannot be achieved without full integration of crop husbandry and an economic form of animal husbandry on the same land. In Asia and the Far East, the form of animal husbandry that demands the cultivation of fodder crops on arable land and the only one which can make that cultivation economic and competitive with the return per hectare from food and cash crops is dairy husbandry based upon productive livestock.

Concentration of Effort in Limited Areas

There are in India, however, a number of projects for the intensification of agriculture that have until now been located and are being operated without due consideration of animal husbandry as an integral part of the new pattern of land use and production. Yet the only places in India where we can expect real intensification of production are in the milk procurement areas around the big dairy plants. By concentration of effort in these areas we may create oases of intensive forms of agriculture such as have not yet been seen in that country. It is rarely possible to spread limited resources of men, money and material over large areas, and the concentration of efforts in the most potentially profitable zones and enterprises is the correct policy. Milk procurement areas provide just these conditions.

Intensification in milk procurement areas is based on the following factors and practices:

(*a*) The cultivation of well-manured and fertilized fodder crops, particularly short-term legumes, especially under year-long or seasonal irrigation, in rotation with food and cash crops on cultivated land. The role of natural grassland is discussed in Chapter V.

(*b*) The provision of an adequate number of bovines sufficiently productive to make this cultivation of green or conserved fodder economic and competitive in financial return per unit area with food and cash crops.

(*c*) The removal from the actual milk procurement area of all non-productive animals that compete for the fodder resources (dry stock, rearing animals, sheep, goats, etc.).

(*d*) Full return of dung and urine to the land.

Even the uneconomic practice of basing the feeding of dairy animals

on concentrates may contribute to increased production Say that a procurement area around a large dairy factory needs 60,000 tons of concentrates per year, mostly obtained from outside the area This represents an importation of some 25,000 tons of farmyard manure rich in plant (and soil) nutrients, being the proportion of the total concentrates fed that are not utilized by the animal

A number of factors are related to the introduction of this new form of agricultural production for which we claim the significant role of catalyst There are psychological factors—the likelihood of acceptance of new farming systems and of fodder cultivation and animal husbandry by cultivators long dominated by the cereal mentality There are the many technical aids that have to be provided, such as fertilizers, improved seeds of authenticated cultivars, water for crop irrigation and stock, machinery for better cultivation and conservation

These factors must all be considered against the background of present land use, of competition for limited resources, and things like the type of ownership of land and livestock, the distinction between animal husbandman and cultivator, security of tenure to promote an interest in maintaining productivity of the farm on a long-term basis to which dairy farming can so well contribute, the availability of capital or credit for investment in the new enterprise, the manner in which rents are paid (dairy development is hampered by share-cropping systems laying stress on a share of the arable crop), the reaction of farmers to co operative ventures in the production phases, and finally, the complex social and religious barriers to efficient development

R H Lush of the Department of Dairying in the University of Tennessee believes that too much emphasis may be placed on the thesis that the better lands, cultivation of fodder crops on the farm, and the conservation and utilization of animal manure are essential in modern dairying Looking back on forty years of change in the United States of America, it may be seen that the better land now goes to food and fibre crops, that concentrates and even hay are moved hundreds of miles, and that animal manure and even legumes are not efficiently used in modern dairying Silage and some pastures are still produced locally An operator with training in cattle management has been a larger factor in success Even proximity of market has not the significance that it once had It may be better to continue the importation of dairy products into some countries that have little of the dairying mentality or facilities for rapid development in the future

this fundamental aspect should be obtained by the agronomists so that the production economists can base their calculations on realistic figures

Agronomic and marketing considerations will govern the type of product to be provided from a milk factory Milk collected in the suburban and rural areas around large urban centres will probably be marketed as liquid milk It may be more costly as it is produced on valuable land, perhaps in competition with vegetables and other high-value horticultural crops, and with expensive labour In the more remote areas the milk will be converted into more readily transportable products The cost of production may be less and seasonal fluctuations in supply may be more acceptable

For a country like India, for example, milk production as part of a regional farming system can be economically justified only if (*a*) the use of part of the cultivated land for fodder crops does not reduce and in fact may increase the overall production of food and cash crops, particularly the former, and if (*b*) it can be shown that fodder crops fed through productive animals can give the cultivator as many rupees per acre from the sale of milk as he obtains at present from his food and cash crops Under favourable conditions in India—fertile land and ample supplies of irrigation water—there is evidence that both these requirements may be met

But it is very different to see how the necessary acres of land may be released from the production of the food grains which are already insufficient to meet the demands of the rising population It is probably already too late to prove on any scale that maximum intensification of agriculture, and hence maximum economic return of food (or plant and animal protein) per unit area, may be obtained through maximum integration of crop husbandry and animal husbandry on the same land The present policy of pouring artificial fertilizers on the exhausted soils of India, poor in structure and low in organic matter, will be followed, with the limited results that may be obtained from this method with crops other than paddy Apart from the shortage of land for fodder production, it is the chronic inability of the milch animals, the so called 'cattle wealth of India', to convert the feeds and fodders efficiently into milk that is the main factor limiting the economic development of the industry The milk that is produced in this inefficient way will become progressively more expensive and out of reach of the purchasing power of a large section of the community

For his talks with farmers, the extension agronomist needs to be

armed with other economic data which are at present not available. There is a standard of milk production per animal at which fodder production becomes economic and competitive with the food and cash crops. This threshold of production is, of course, related to the price paid to the producer for his milk, and to other factors. We need to know the costs, at different levels of technological advancement of farmers, of establishing fodder crops and pastures (especially costs of cultivation, fertilizers, manures, seeds, fencing), or of management (especially costs of irrigation layouts and water supplies) and of harvesting. We may not always be correct in saying that it is more economic to grow and feed green or conserved fodder than to purchase concentrates. There are indications that this claim is correct up to a certain level of intake but we need confirmation in the form of comparative costs of kilogrammes of plant protein and for total digestible nutrients from the various alternative sources.

Trials conducted in 1963–4 at the Southern Regional Animal Nutrition Research Station at Bangalore have provided an interesting cost comparison between two contrasting systems of feeding dairy animals.*

(*a*) Feeding concentrates for maintenance and production, plus crop residues *ad lib.* and only 5 kg. green—cost of feeds only to produce 1 kg. fat-corrected milk (f.c.m.) = 25 paise (100 paise = 1 rupee).

(*b*) Replacing most of the concentrates with protein-rich Para grass fed *ad lib.* plus 1 to 2 kg. straw and 1 to 2 kg. molasses—cost of feeds only per kg. f.c.m. = 15 paise, or 17 paise with Guinea grass, because of higher costs of cultivation.

Although the costs of production of the grasses have increased somewhat since 1963–4, the concentrates and crop residues have increased to such an extent that the figure under (*a*) above should now be 50 paise per kg. f.c.m.

The economics of fodder production in terms of inputs and outputs must be considered separately for the rural areas, and for the well-organized farms, cattle settlements and milk colonies.([129]) In the rural areas the surveyor is faced with the illiteracy of the cultivators, the small fragmented holding, the absence of records of labour used and costs of seeds, manures and fertilizers. With the cultivators' ignorance of the quantitative aspects of their business and a natural reluctance to disclose the details to casual inquirers, it is difficult for an economic surveyor to obtain reliable information through periodic visits and the filling in of questionnaires. This can be done only by taking a random sample of

* Figures based upon rupee before 1966 devaluation.

privately operated units and maintaining cost accounts with the help of trained investigators

Information on costs may be obtained with regard to interest on investment in livestock and the cost of maintaining them (other than feed costs), to the construction of buildings and to the many incidental costs that arise in an efficiently operated dairy enterprise If from these studies the percentage of the ultimate selling price of the milk represented by the initial costs of production can be defined, it becomes possible to recognize the weak spots, and finally to reduce all these costs to a minimum compatible with efficient production and utilization of feed converted through efficient animals

Efficiency of Conversion

More facts to emphasize the importance of having productive animals as efficient and economic converters of feeds and fodders may be obtained from a comparison of figures of costs of production per kg milk in relation to annual production of milk per animal These are available from the experimental farm at Terbol in the Lebanon, where a remarkable Holstein herd is maintained under excellent conditions of management and nutrition The average production per animal in 1954, 1960 and 1961 was 3,704, 5,510 and 6,300 kg per annum respectively The costs of production per litre of milk for annual productions ranging from 1,000 to 6,000 kg per animal have been calculated (Table 10)

TABLE 10

Lebanon Costs of milk production at Terbol, in relation to annual milk yields

Annual production (in litres)	Cost of production per kg. (in piastres)
1 000	94 00
1,500	60 33
2 000	50 60
2 500	43 25
3 000	36 00
3 500	32 49
4 000	29 36
4 500	27 00
5 000	24 90
5 500	23 26
6 000	21 93

Figures for costs of imported milk are not available for purposes of comparison. It may be estimated that the costs of production on an average farm in the rural areas of the Lebanon would be between 32 and 36 piastres, considering that the administrative and managerial costs at Terbol do not apply. The small farmer should also deduct the value of the manure when calculating his costs of production.

Economics of Dairy Husbandry

As the promotion of dairy husbandry is a relatively recent development in tropical agriculture, it is not yet possible to present economic data on which comparisons may be made and conclusions drawn. It is doubtful whether it will ever be possible on more than a limited local scale, having regard to the wide varieties of agroclimates, sources and types of feeds and fodders, lactation yields of livestock and intensity of enterprise in the regions reviewed here.

Caribbean and Latin America

One such example of a relatively limited approach is to be found in a study[146] of the economics of milk production in Trinidad, Jamaica and Surinam, with reference to six different types of enterprise, three actually in existence, three more in the nature of proposals, with estimated figures:

(*a*) An experimental dairy farm of peasant type, operated by Imperial College of Tropical Agriculture, Trinidad, from 1949–52.
(*b*) An intensive pilot dairy farm in Surinam, for the period of 1958–60.
(*c*) University of West Indies dairy farm in Trinidad, for the period 1961–3.
(*d*) A recently established pilot dairy farm at Waller Field, Trinidad.
(*e*) A medium-size dairy farm in Trinidad (proposed).
(*f*) A medium-size dairy farm in Trinidad (proposed).

The economic characteristics of the various enterprises and different parameters are given in Table 11. The overall figures given for Surinam are actual figures, those for Trinidad have been calculated by the author on the basis of data for that island, where salaries and wages, price of concentrates and other costs differ from those in Surinam. It is possible on the basis of the six actual and theoretical enterprises chosen to draw some conclusions regarding size of the units, number of workers

TABLE 11

Caribbean and Latin America Economic data from different types of dairy farming enterprise(146)

Name of Unit	Size in acres	Labour income/ man $	Stocking Rate cows/ acre	Labour and Management Income $ /Farm	Labour and Management Income $ /Acre	Employment Men/ farm	Employment Acres/ man	Gross Output/ $100 labour $	Output/acre Gross $	Output/acre net $	Capitalization farms/ $	Capitalization acre/ $	Capitalization /job $	Management and Investment return on capital %	Cost of production cents/ gallon $
(A) Peasant Experimental Dairy Farm, Trinidad	5	1,460	1 0	1,597	319	1½	3½	156	570	440	6,100	1,220	4,070	1 25	1·08½
(B) Pilot Dairy Farm, Surinam	5		1·4			1	5								
(i) Surinam prices		1,060		1,688	338			374	792	574	6,860	1,372	6,860	15	85½
(ii) Trinidad prices		1,460		1,669	334			273	798	554	6,868	1,374	6,868	8	85½
(C) UWI Field Station Dairy, Trinidad	15	2,920	1 7	6,727	448	1½	12	320	866	743	27,500	1,832	22,000	14 5	78
(D) Pilot Dairy Farm, Wallerfield, Trinidad	20	1,825													
(i) without irrigation			0 75	1,815	91	1	20	298	271	224	15,400	770	15,400	5	84
(ii) with irrigation			1 0	1,940	97	1½	13½	370	362	298	22,400	1,120	15,000	5	83½
(E) Medium-sized Dairy Farm, Jamaica	25	2,920	1 0			1	25								
(i) Jamaica prices				7,488	374			498	580	535	34,560	1,380	34 560	18	58
(ii) Trinidad prices				6,047	302			462	540	470	30,460	1,220	30,460	15	59
(F) Medium-sized Commercial Dairy Farm, Trinidad	35	3,285	1 2	6,317	180	1	35	486	456	400	45,680	1,300	45,680	11 5	62

employed per hectare, the relatively high rate of investment per hectare, the rate of return from labour and the cost of production of milk.

Non-mechanized small-scale enterprises based upon stall feeding do not appear to be capable of bringing in sufficient revenue for a family, nor sufficient interest on the capital invested, unless the milk is subsidized. Enterprises based on pastures appear to be economically viable, provided that at least 8 hectares of good land are available. The production of fodder to be used in intensive dairy production with a sound technical basis can provide sufficient income to the farmer in the Caribbean, if the undertakings are of medium size with a large capital investment and intensive use of labour. Any other type of fodder production, even if intensive and for the feeding of cattle for beef or sheep for mutton, cannot compare with dairy farming from the economic point of view.

India

A project to study and demonstrate the economics of specialized dairy farming in comparison with other systems of farming in rural areas was started at the National Dairy Research Institute, Karnal, Punjab, in October 1962 and is to continue until June 1968. The technical programme is as follows:

Four units of about 7 acres each are to be set up in a contiguous block of 10 acres, comprising:

(*a*) arable farming unit with one Tharparkar cow, its follower, and one bullock;

(*b*) specialized dairy farming unit with seven Tharparkar cows, their followers and one bullock;

(*c*) specialized dairy farming unit with seven Murrah buffaloes, their followers and one bullock; and

(*d*) mixed farming unit with four Tharparkar cows, their followers and one bullock.

Well-drained, level and fertile land will be obtained, irrigated, adequately manured and cropped at not less than 200 per cent intensity in a system typical of local farming conditions.

In the specialized dairy farming and mixed farming units, all cattle feeds and fodders would be grown on the land, none to be purchased and none grown for sale. If the quantity should be more than the requirement, more milch animals should be introduced. In the mixed farming and arable unit, the requirements of the animals should be met

by fodder production within the unit, and the rest of the land should be used for remunerative crops

Concentrate feeding would be reduced to a minimum or eliminated If absolutely essential, a small amount may be raised in the cropping programme, or a grain or cash crop may be grown to provide cash for the purchase of cake or bran

Farmyard manure produced in each unit will be used to manure that unit None will be purchased from outside The additional requirement of fertilizers will be met by the purchase of artificial fertilizers

One bullock will be maintained in each unit, but bullocks will be used in pairs for field operations One man will be employed in each unit with additional casual labour as required

The fodders grown in the different units will be chemically analysed

High yielding animals from the locality will be introduced, but any animal that shows a fall in yield will be removed and replaced by another Calves at heel and followers up to 20 per cent will be maintained in each unit All calves will be kept up to weaning, say 6 months, and thereafter selected female calves will be reared to maturity, the remainder being sold and their value recorded against their respective unit An attempt will be made to wean calves as early as possible All animals will be tested for tuberculosis, brucellosis and other diseases at regular intervals and any affected animals will be removed and replaced

As far as possible animals are to obtain most of their feed from grazing with stall feeding to be adopted supplementary to grazing or during the off season In the specialized dairy farming units strip grazing by animals with electric fencing will be encouraged

Natural service or artificial insemination through bulls of good pedigree will be arranged

Soil samples will be taken for analysis of the cumulative effects of each type of farming in terms of available NKPCa, etc , at the end of each year

Detailed records of cost of cultivation of crops and the milk and butterfat are to be maintained for each unit separately, and the following miscellaneous records are to be maintained

(a) milk production,
(b) cultivation and manuring of crops,
(c) feeding of animals,
(d) stable operations

Various items of expenditure and income in respect of all four holdings for the year 1964–5 are given in Table 12 It will be seen that in

respect of total income, total expenditure and net annual income, the four holdings came in the following descending order:

(1) dairy farming (cows);
(2) mixed farming (cows);
(3) dairy farming (buffaloes);
(4) arable farming (single cow).

It will be seen that the dairy farming unit again gave highest net income, whereas the arable unit which was bracketed with it in the previous year gave lowest net return in 1964–5. The mixed farming unit stands second in respect of net income, but its arable portion was observed to be comparatively less remunerative than the dairy farming part. There are certain reasons which may explain the comparatively low net income from the arable unit. Although the dairy farming (buffalo) unit showed enhanced profits in 1964–5, it could not compete with the cow unit because the daily average milk yield was only 4·1 kg. as compared to 7·2 kg. with the cows. The low milk yield in the buffalo unit is partly due to the fact that two buffaloes ceased their lactation abruptly after the death of their calves, a trouble which arises due to their maternal instinct. Past experience has shown that such buffaloes, which have a long dry period and less drain on their body reserves, make up the deficiency in one lactation by good production in the next lactation.

The carrying capacity of the land in each of the three units was invariably more than one animal per acre, even after growing concentrates in each. Because of this, the number of animals in the dairy farming unit will be increased proportionately, whereas in the mixed farming unit the area under fodder would be reduced.

While a pair of bullocks would generally be sufficient for an area of 15 acres under double cropping, an additional pair of bullocks or even limited use of a tractor would make the exploitation of land more efficient, particularly in erratic monsoon seasons.

The yield obtained from various crops grown in the different holdings was generally above the standards of local farming. It can be demonstrated to the farmer that fodder crops of superior quality may be grown at a much cheaper cost and utilized efficiently by good quality milch animals to produce abundant quantities of milk at low cost. Although the fertility of the land assigned to the dairy farm units (cow and buffalo) appeared to be raised following the application of greater quantities of farmyard manure and the inclusion of a greater acreage of leguminous fodder crops in their cropping programme, it is nevertheless difficult to make a sound comparison since fertility is governed by so many different factors.

It is, of course, important not to draw firm conclusions on the basis of one year's results, or even on the early years in the series. The final results at the end of the experiment in 1968 will be awaited with great interest. One must introduce a word of caution, however, in considering comparisons of farming systems on the basis of one unit under each system. Finney and Panikkar[36] drew attention to this in their review of the results of an earlier series of comparisons arranged by ICAR between mixed farming and other types of agriculture.

TABLE 12

India. Expenditure and income (in rupees) in the different units of specialized dairy farming scheme, Karnal, Punjab (1964–5)

EXPENDITURE

Items	Arable Farming (Cow)	Dairy Farming (Cows)	Dairy Farming (Buffalo)	Mixed Farming (Cows)
1. Feed				
(i) Dry fodder (previous balance)	18 30	103 75	123 80	57·30
(ii) Concentrates (purchased)	92 25	1748 90	1100 25	962 25
2. Farm operations	1655 80	1358 25	1564 75	1319 80
3. Recurring expenditure	944 45	537 80	505 75	664 20
4. Depreciation on animals	160 00	1120·00	—	640 00
5. Depreciation on farm and dairy equipment	61 75	110·40	115 55	90 05
6. Labour on stable operations	85 30	672 10	614 30	388 65
Total	3017 85	5651 20	4024 40	4122 25

INCOME

Items	Arable Farming (Cow)	Dairy Farming (Cows)	Dairy Farming (Buffalo)	Mixed Farming (Cows)
1. Sale of crop and crop residues				
(i) Dry fodder	95 85	131 80	—	51 80
(ii) Green fodder	1546·00	1022 30	180 25	828 65
(iii) Concentrates	—	—	—	—
(iv) Other crops	2919 85	243·00	287 40	919 10
2. Balance of crops and crop residues on 1 7 1965	125 50	347·90	928·05	654 90
3. Sale value of				
(i) Milk	586 60	9760 70	6090 65	5812 65
(ii) Calf	—	—	—	—
(iii) Hides, etc.	—	—	—	—
4. Manure (in balance)	9·00	25 00	20·00	18·00
Total	5282 80	11530·70	7506 35	8285 10
Net income	2264 95	5879 50	3481 95	4162 85
Income per animal/acre/year	323 56	839 93	497 42	594 69

Taiwan

Some indication of the economic feasibility of adding dairying to farms in Northern Taiwan having some dryland suitable for growing fodder crops may be gained from a field survey of dairy farms and crops farms in Yuan Mei Township of Taoyuan Prefecture, conducted in 1959 by S C Hsieh and Y T Wang of the Rural Economics Division of the Joint Commission on Rural Reconstruction ([98]) A total of sixteen crop farms with comparable amounts of arable land, eight of which had dairy enterprises and eight without, were selected The farms were similar in most respects, except for livestock numbers and investments in the dairy enterprise (Table 13)

TABLE 13

Taiwan Land, labour, livestock and capital investment of 16 crop farms with and without dairy enterprises—1959

Item	AVERAGE PER FARM	
	8 Farms without Dairying	8 Farms with Dairying
Cultivated land (hectares)	2 26	2 43
Family size (persons)	11 0	11 0
Farm workers (man equivalent)	2 7	2 8
Livestock raised	1 0	0 9
Cattle—head	1 0	0 9
Hogs—head	6 8	9 5
Poultry—head	61 0	72 0
Dairy cows—head	0	2 8
Buildings and implements NT$	15 117	20 686
Fixed capital investment in dairy enterprise (mainly cows, special buildings and equipment) NT$	—	53 383

The farm with dairying had slightly more hogs, poultry and investment in buildings and implements in addition to the investment in the dairy enterprise The annual production costs per dairy cow including labour, feeds purchased and home grown, medicines and depreciation on dairy cows and buildings was NT$ 10 518 The barnyard manure produced was worth NT$ 1,136 and the value of a calf produced averaged NT$ 411 or a total for by products of NT$ 1,547, leaving a net production cost of NT$ 8,971

The comparison of economic factors on these farms shown in Table 14 indicates that substantially more total as well as cash farm income was obtained on the farms that diversified with a dairy enterprise The total input and cash input were greater on the dairy farms because of

the heavy investment required for expensive dairy cows and some additional buildings and equipment. Nevertheless the total cash returns per dollar cash input were nearly 30 per cent higher, $1,89, as compared to $1,49, on the farm without a dairy enterprise. Less fertilizer was used and less hired labour employed on the dairy farms. However, about 21 per cent more labour was used on the dairy farms and family labour was better utilized throughout the year.

TABLE 14

Taiwan. Comparison of input-output relationship between crop farms with and without dairy enterprises—1959([95])

	CROP FARM WITHOUT DAIRY		CROP FARM WITH DAIRY	
	Amount NT$	%	Amount NT$	%
Total income				
Crop production	28,920	100	37,716	130
Livestock production	12,310	100	14,770	120
Dairy production*	—	—	30,641	—
Total (A)	42,230	100	83,127	202
Cash income:				
Crop production	7,966	100	8,269	104
Livestock production	11,088	100	12,563	113
Milk production	—	—	20,010	—
Total (B)	19,054	100	40,842	214
Total input:				
Labour	11,969	100	14,268	119
Working capital	14,257	100	36,145	254
Fixed capital (flow service)	1,357	100	6,737	496
Total (C)	27,583	100	57,150	207
Cash input (D)	12,749	100	21,630	170
Fertilizers:				
Self-supplied	1,223	100	2,208	181
Purchased	4,577	100	3,918	86
Total	5,800	100	6,126	106
Feeds:				
Home-grown	2,929	100	14,319	489
Purchased	4,287	100	13,690	319
Total	7,216	100	28,009	388
Labour:				
Self-supplied	8,540	100	11,265	132
Hired	3,429	100	3,003	88
Total	11,969	100	14,268	119
Total income/Total input A/C	149		145	
Cash income/Cash input B/D	149		189	

* Including milk, production of calves and increased value of dairy cows.

Since large amounts of barnyard manure were produced by cows on the dairy farms, more compost manures were used. Even though an average of 215 kg. or one-third less commercial fertilizer was used on the dairy farm, yields of paddy rice are 20 per cent greater (Table 15), and these results are likely to be cumulative as time goes on. Forage crops play an important role in the dairy enterprise. On some of the farms on which they are included in the crop rotation, additional increases in crop yields can be expected in future from the beneficial effects of the additional organic matter and nitrogen supplied.

TABLE 15

Taiwan. Yield of paddy rice and use of fertilizer on farms with and without dairy enterprises(98)

Item	AVERAGE PER FARM 8 farms Without Dairying	8 Farms With Dairying
Yield of paddy rice per crop kg/ha	3,031	3,626
Fertilizer used:		
Chemical fertilizer kg/ha	653	439
Compost manures kg/ha	1,966	5,373
Total value NT$	1,466	1,356
Percentage distribution of fertilizer used:		
Chemical fertilizers	89	65
Compost manures	11	35

Australia—New South Wales

Real possibilities for doubling or trebling pasture productivity can be seen in the region known as the North Coast of New South Wales, a borderline zone between temperate and subtropical conditions. Swain(148) has described the actions taken and now being recommended to dairy farmers in the area, and has analysed the costs and returns involved in this development. Butter production in the region in 1963 was about 60 per cent of the total for New South Wales and 14 per cent of the total Commonwealth production. The region also produced 14 per cent of the State total of beef and veal, and had 31 per cent of the State total of breeding sows. However, in the North Coast portion surveyed in 1958–9, 16 out of 61 sample farmers had a net cash income of £A800 per annum, and in 1960 the number of registered dairies had fallen to 81 per cent of the 1939 total, and number of cows to 84 per cent of the 1939 level.(6, 7) The North Coast Agricultural Research Council sum-

marized the problem as follows restricted pasture production, inability of naturally occurring species to meet the requirements of the animals, widespread deficiency of nitrogen in grass-dominant pastures, and the unprofitability of importing expensive feed on the farm

Following the Richmond-Tweed pasture research programme, it became possible from 1961 onwards to propose new farming systems These were based on a combination of the most promising tropical and temperate species to provide a continuity of feed throughout the year—a 'feed year' or pasture and fodder calendar geared to a temperate winter and a subtropical summer (see Fig 4)

Two major utilization studies were designed to compare two management systems (1) a control representing typical unimproved district farming practice in which spring calved cows were grazed on the summer growing grass-dominant pastures alone at a cow per 0 8 hectare, and (2) a new system where 60 per cent of the property was developed with the three feed-year species, *Glycine javanica*, vetch and subterranean clover, in approximately a 1 1 1 ratio, cows were calved in early summer and the stocking rate has been increased to a cow per 0 7 hectare The production from the cows under the new system increased by 70 per cent (Table 16) Figure 5(a) shows the production gains which were obtained from only one third of the improved areas required in the complete plan for three commercial farms—the production increases of 38, 24 and 22 per cent respectively are regarded as very encouraging Figure 5(b) shows that there has been a large increase in the amount of forage available on these properties due to the introduction of the improved species

Broad estimates of costs and returns for one of the commercial farm case studies are given in Table 17 When the plan is fully implemented, extra costs of about £A545 will be incurred each year, allowing for depreciation and interest on additional machinery, costs of pasture maintenance and annual sowings of vetch The budget in Table 17 assumes a 20 per cent increase in rate of stocking and 97 kg butterfat per cow which would result in a net income gain of £A615 per year—regarded as a conservative expectation These results apply to the red basaltic soils on the chocolate and alluvial soils, increased cash surpluses of about £A1,000 per farm per year are predicted New studies at Wollongbar will investigate these types of fully developed pasture systems under high stocking rates with dairy cows Theoretical estimates based on pasture yield and animal requirements indicate that a system of this type should produce 270 kg butterfat per hectare—a great advance on the

present North Coast average which ranges from 22 to 112 kg. per hectare Credit problems have still to be resolved, but bankers now have some tangible criteria on which to base their loans.

TABLE 16

New South Wales. Feed year production, Wollongbar, 1963–4. Butterfat production of control and new system group cows

	Control	New System
Number of cows	12	14
Days in milk	255	267
Butterfat (kg)		
per group	913	1,539
per cow	76	110
per hectare	91	154

TABLE 17

New South Wales Analysis of net income gains using assumed production response. Farm No. 3—Red basaltic soil commercial farm case study—Father's property

Year	Actual or assumed farm production, butterfat	Value of added production over base period	Outlays for development	Income gain or loss	Income gain or loss corrected for tax	Overdraft or Credit balance for project*
	kg	£A	£A	£A	£A	£A
1962–3	3,188	—34	426	—460	—400	—411
1963–4	4,221	+462	714	—252	—212	—653
1964–5	5,040	+850	764	+86	+ 72	—618
1965–6	5,670	+1,160	613	+547	+407	—236
1966–7	5,670	+1,160	545	+615	+455	+220
1967–8	5,600	+1,160	545	+615	+455	+718

* Cumulative balance from year to year with interest added at 6 per cent on average amount outstanding during year.

† £A = Australian pound Twenty-five shillings Australian equals twenty shillings or one pound sterling, but from February 1966 $A100 = £A50 = £40 sterling = US$112

Chapter XI

SYSTEMS OF BOVINE HUSBANDRY

The Five Principal Categories

Many types and standards of agrarian structure and farming systems are to be found in tropical and subtropical latitudes, but it may be said that the methods of keeping dairy animals fall into one of the following categories:

(a) The cowkeeper in urban and suburban areas who keeps his animals in sheds with no land attached, who purchases all his fodder and who keeps cows or buffaloes only while they are in milk.

(b) The milk colonies and cattle settlements containing thousands of animals removed from urban and suburban areas to hygienic conditions and good standards of management

(c) Milk producers in rural areas who each maintain up to five animals as an incidental adjunct or an integral part of their farming enterprise, with the production of food and cash crops as the primary activity

(d) Specialist dairy farmers in rural districts who use their land primarily for pasture and fodder production, and

(e) Rural dairy farms operated by government in regions where no tradition of dairy farming already exists

For hygienic milk production, the urban sheds of tropical cities are quite unsuitable This type of dairying frequently depends upon the purchase of the better stock from rural areas, to be milked out and then sold for slaughter This system represents a serious drain on the breeding areas In addition, the bad housing conditions in most urban dairies are conducive to the spread of diseases transmittable to man, such as tuberculosis and brucellosis Dairies situated outside the suburban limits of large cities, if operated on correct lines, should be an objective which is logical and economic

Hans Pedersen of FAO discussed questions relating to methods (b) and (c) above with special reference to India, at the XVIth International

Dairy Congress in Copenhagen in September 1962. He stated that Aarey Milk Colony near Bombay was designed to take a considerable concentration of milch animals from the city area, but with insufficient land for an integrated farming policy. With the exception of green fodder from Para grass grown at the Colony, all the feeds, fodders and hays have to be purchased. The disposal of manure is a major problem, but the Railway Board has granted a 50 per cent concession for freight up to 480 km. from Bombay. With an additional subsidy from Bombay Milk Scheme, the manure will not cost more than Rs. 9 per ton at the destination railway station.

An area of 3,600 acres would be necessary to provide 15,000 milking animals giving 2,500 litres per lactation (the dry animals are taken to the Dry Stock Farm at Palghat) with 30 kg. green fodder per day, assuming yields of 50,000 kg. per acre green per annum. The actual acreage of Para grass at the Colony is very much less, but the amount of concentrates fed for maintenance and production is three times the amount generally recommended. The situation at Madhavaram Milk Colony (Madras) is similar. Most of the green fodder is being purchased from the Municipal Sewage Farm near by, and all the concentrates and dry fodders are being purchased from outside. The disposal of manure is again a problem. Haringhata, near Calcutta, is in a different category—a cattle settlement involving a certain integration of animal husbandry and agriculture. There is enough cultivated land to grow much of the green fodder required, and the area is being progressively increased; full and effective use of the manure is possible within the unit itself.

Although both these systems are successful and although the colony or settlement plan may be the most practicable under certain conditions, they do involve 'the loss of the dairy cattle as a key factor in a highly complex, interdependent and balanced system of integration of soil, crop, animal and man which, in the western world, has resulted in an ever-increasing standard of agricultural and animal productivity as well as of human nutrition.' Milk colonies and in particular cattle settlements should not be entirely condemned, but should be regarded as a means to an end, generally not the end itself. The choice is between the short-cut they represent, and the slow and complex integration of dairy farming into the traditional rural life and agrarian structure.

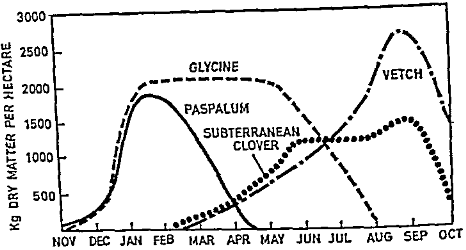


FIG. 4. New South Wales—Feed Year, Wollongbar. Seasonal distribution of dry-matter yields of *Paspalum*, *Glycine javanica*, subterranean clover and vetch. Yields based on a mean of small plot data, 1952–61.

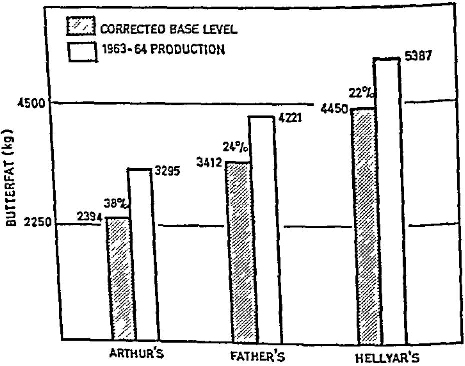


FIG. 5a. Butterfat production of herds on three red basaltic soil commercial farm case studies, 1963–4 lactation.

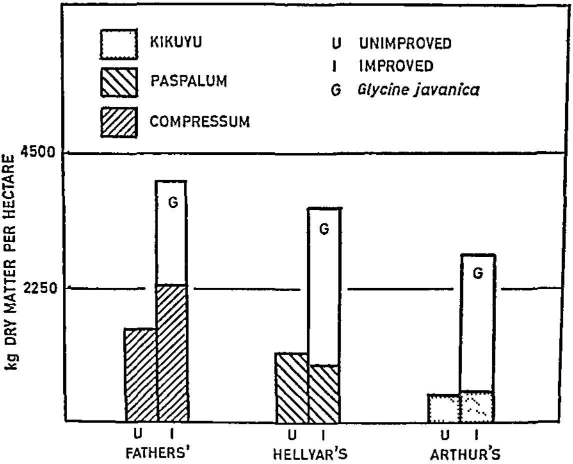


FIG. 5b. Dry matter production of natural grass pasture, alone, and in association with a tropical legume, *Glycine javanica*, on three red basaltic soil commercial farm case studies.

Rural Dairy Farm

One way of starting this radical change in those parts of the tropics and subtropics where rural communities have no experience of dairy husbandry in the modern meaning of the term is to establish Rural Dairy Farms to be operated by Government Departments of Animal Husbandry or Dairy Development These farms would be centres for milk production, at which Government officers would obtain experience in animal breeding and management and in fodder production and utilization for one of the most exacting forms of animal husbandry The farms would also provide advice and demonstrations to members of village milk societies in their area, in addition to improved animals and/or facilities for artificial insemination, and also seeds and planting material of fodder crops and equipment on loan for irrigation, hay-making and the mixing of the ingredients of concentrate feeds and oil-cakes

A Rural Dairy Farm may be 100 acres or more in size, preferably all or mostly irrigable, with well-designed cowsheds made of locally available material set at a level above the grass fields in order to allow for the flow of the cowshed wash by gravity to nearby fields of Para grass, for example The rate of stocking per acre (all stall-fed) on newly reclaimed land might commence at two milking animals and rise steadily to higher rates when the soil fertility is built up

Let us give a concrete example of production and carrying capacity on such a farm in Orissa, after the initial period of establishment is over, in a region where the major African fodder grasses, Guinea, Napier and the Napier × finger millet hybrid and Para (*Panicum maximum*, *Pennisetum purpureum* × *P typhoides*, and *Brachiaria mutica*) may be grown Other units may be designed for different conditions and different sources of feeds and fodders

(i) *Area* 100 acres, made up of
- 80 acres irrigated perennial fodder grasses
- 10 acres seasonal fodder like maize, sorghum, berseem, lucerne (as annual)
- 10 acres buildings, roads, etc

(ii) *Grass Production*

	Tons
50 tons green per acre on 80 acres	4,000
10 tons green per acre on 10 acres	100
	4,100

(iii) Number of animals which would be maintained assuming a daily requirement of 30 or 40 kg. of green fodder, or an annual requirement of 12,000 and 16,000 kg. respectively.

$$\frac{4,100,000}{12,000} = 350 \text{ animals or } 3{\cdot}5 \text{ per acre.}$$

$$\frac{4,100,000}{16,000} = \text{approx. } 250 \text{ animals or } 2{\cdot}5 \text{ per acre.}$$

When the production of green grass per acre increases above the figures used in (ii) above, the number of animals per acre will also increase, up to five or more.

Young stock up to a certain age would be kept at the farm, but the dry animals and older young stock up to age of calving would be maintained on a dry stock farm within reasonable distance of the main farm. In this way would be developed a focus for dairy development in all its aspects in rural areas where there is already no experience in this demanding type of animal husbandry, plus a production centre from which may be obtained a steady flow of milk for a plant within collecting radius.

Farm Planning

In designing new or deciding to maintain indigenous systems of bovine husbandry for economic milk production, it is necessary to remember, as argued elsewhere, that the feeding of productive dairy cattle in the tropics is likely to be increasingly in stalls. Grazing of artificial stands of *grass and/or legume is good neither for the animals nor the pasture.* Even in the 'grassy' environments of Great Britain and New Zealand, it is now debatable whether zero grazing is not going to be the system of the future. It is quite inconceivable that 40 per cent of the large yields of herbage obtainable in the tropics should be lost by trampling of the grazing animal or by poisoning with its droppings of dung and urine.

At the other extreme, there are still people who consider that it is technically and economically feasible to produce milk on range land or natural tropical grasslands and pastures, as will be seen in some of the Country Studies. It is only relatively recently in India that it has been realized that the village pastures and natural grazing or hay lands are of only very secondary importance in the production of milk.

The great need in the developing countries is for farm planning designed to incorporate dairy husbandry of an appropriate level of intensification with older farming systems which lacked the components of

animal husbandry and fodder production In India there have been major developments in irrigation, but insufficient follow up in advising cultivators how they may change their farming systems and crops to utilize the water fully and to show how well dairy farming would fit into the new farming plans Town mayors in Japan have expressed the urgent need for specialists in planning small farming units for dairy production to visit the farmers in their municipalities, so that they may be put on the right lines from the start. Those who have attacked the rice mentality of south east Asia and the Far East, which dominates so much thought, research, extension and policies of human nutrition, are greatly encouraged by the figures for Taiwan given in Tables 13, 14 and 15 This shows the results of incorporating dairy farming with its partner, fodder production, into formerly monocultural units Farm planning has for years been given great significance in Southern Rhodesia The results in Figures 6 and 7 show the effect of major adjustments in the planning of a maize/cattle farm near Salisbury Although the data relate to the production of beef, they might also apply to a change from the extensive type of cattle husbandry to economic dairy farming, with certain further refinements, and provided there is a good market for milk and/or dairy produce

It is not intended to indicate that these four examples are in any way comparable, except in showing that the redesigning of farm enterprises is an essential part of dairy development wherever it is undertaken, and that the officers who are to assist farmers in this planning should have a rather special type of training and experience

2,000-ACRE MAIZE FARM

Maize and 3-year-old Slaughter Stock

- Arable 750 acres
  - Maize 375 acres
    - Grain 5,625 bags
    - Stover Winter roughage · 60 head 30–36-month-olds
  - Green crop 375 acres
- Purchased feeds
- Veld 1,250 acres
  - Grazing 60 head 6–18-month-olds
  - Grazing 60 head 18–30-month-olds

Beef production

Age, months	*Weight lb.*	*Daily feed*
6	400	Veld grazing + stover + 2-lb. cubes
12	500	Veld grazing
18	650	Veld grazing + stover + 3-lb. cubes
24	750	Veld grazing
30	900	
36	1,000	Stover + 4-lb. cubes

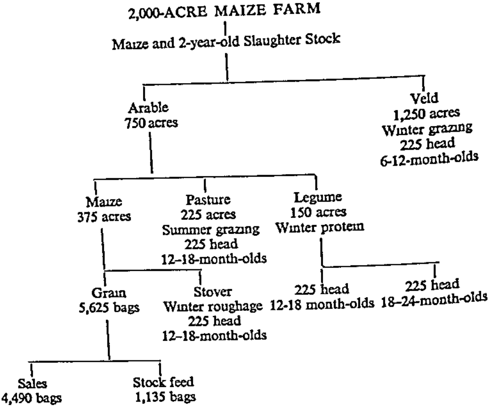
Dressing 525 lb. C.D.W. S.T.D.A. at 155/– per 100 lb.

Gross return £40 0s. 0d. per head

Requirements	£	*s.*	*d.*
Weaner	14	0	0
Interest @ 6% for 2½ years	2	2	0
1st winter supplement 300-lb. cubes	3	15	0
Interest @ 6% for 1½ years		6	9
2nd winter supplement 450-lb. cubes	5	12	0
Interest @ 6% for 1 year		6	9
3rd winter supplement 480-lb. cubes	6	0	0
Dip 2½ years @ 5/– P.A.		12	6
Dosing inoculation and vet		5	0
Fencing: 8·5 miles 8/– P.H.P.A.	1	0	0
Water: 2 points 8/– P.H.P.A.	1	0	0
Labour: 2 men 16/– P.H. P.A.	2	0	0
Total	37	0	0

ANNUAL RETURN FROM BEEF 3 × 60 = £180

FIG. 6. The effect of a change in farming practice on a maize-beef cattle farm near Salisbury, Southern Rhodesia, before replanning.



Beef production

Age, months	*Weight, lb*	*Daily feed*
6	400	Veld grazing + 20 lb legume silage
12	500	Pasture grazing
18	800	Stover + 40 lb legume silage + 10 lb maize meal + 3 oz. urea
24	1,000	

Dressing 525 lb C.D W R.B at 180/– per 100 lb

Gross return £47 0s 0d per head

Requirements	£	s	d.
Weaner	14	0	0
Interest @ 6% for 1½ years	1	5	0
1st winter supplement 1½ tons	1	19	0
Interest @ 6% for 1 year silage		2	6
Summer grazing	5	4	6
2nd winter supplement 2 tons silage	2	12	8
5 bags maize meal	7	10	6
18 lb urea		7	6
Dip 1½ years @ 5/– P.A.		7	6
Dosing inoculation and vet		2	6
Fencing 10 miles 4/2 P H. P.A.		6	3
Water 2 points 3/6 P H. P.A.		5	3
Interest on summer grazing for 1 year		6	4
Labour 2 men 7/6 P.H. P.H. P.A.		11	3
Total	35	0	9

ANNUAL RETURN FROM BEEF 12 × 225 = £2,700

FIG 7. The effect of a change in farming practice on a maize-beef cattle farm near Salisbury, Southern Rhodesia, with new cropping system.

Chapter XII

DAIRY DEVELOPMENT: COUNTRY STUDIES

Selection of Countries in Four Major Regions

The selection of countries in the four major regions has been based primarily upon such information as was available. The omission of any particular country should not be taken as a reflection on conditions in that country, but rather as an indication of difficulty in finding sufficient data in the short time available. More data should be available from the Caribbean and Latin America, particularly with reference to Jamaica. Africa south of the Sahara has only recently come into the dairy development picture. It is hoped to extend the geographical scope of the Country Studies in a subsequent edition.

As stated elsewhere, the developing countries (in which category Japan should not now be included) covered in this section represent a good cross-section of conditions outside the truly temperate regions where milk production is an established part of agriculture (Table 1). Most of the conditions described are tropical and subtropical; there are departures from this classification in respect of high altitude areas in the tropics, or of countries in the semi-arid Near East, where summers are subtropical and irrigation is essential, or of Japan with its alternation of general climate between sub-arctic and subtropical within a complex microclimatic pattern. Where possible, the essential meteorological data are given, even if this makes the section somewhat unbalanced as between one country and another. It would be desirable and correct to give these data for all countries.

MEDITERRANEAN AND NEAR EAST

TUNISIA

An FAO/UNICEF Mission visited Tunisia in January 1963 to study

the development and organization of the dairy industry in Tunisia as a whole, to estimate the potential production from cows, sheep and goats, and to consider the problems which have to be faced if rational development is to be achieved ([62]) The Mission studied the situation in the three zones into which Tunisia is usually divided, namely, the North, situated to the north of the line Kef-Hammamet, the Centre, situated between that line and Sbeitla-Mahdia, and the zone of the Oases situated in the South

The North, which contains 50 per cent of the population of Tunisia, was first considered to have the potentiality to meet its own requirements, and also to provide feeds and fodder for the milch animals located in the other zones This idea of transporting fodder from the North to the Centre and the South has been abandoned, however, because of the high cost of transport, which makes the fodder unit more expensive than the same unit produced under irrigation in the irrigated perimeters in the Centre and South The fodder economy of the Oases depends primarily upon irrigated fodder (mainly lucerne) and upon spineless cactus grown dry in areas down to 100 mm rainfall and to be used as a reserve for summer and periods of severe drought The use of fodder grown in the North can be justified only during periods of extreme hunger, and then only for some weeks, otherwise the cost of this feeding can quickly exceed the capital value of the sheep

The great diversity of the Tunisian climate (Table 18) and the wide variations in rainfall, as well as its variable geographical distribution, are the cause of considerable fluctuations in milk production from one season to another, and in different years Because the ecological conditions are not ideal for the production of cow milk, the high-yielding dairy herds must be limited to the areas best adapted to such a type of animal husbandry, and must be in charge of qualified personnel But the ecological conditions are not the only factors limiting dairy production, the question of markets is also very important In the extreme north, the areas around Sedjenane, Djebel Abiod and Tabarka have excellent ecological conditions for dairy production, but they are too far from markets to be of any promise In addition, these areas are very undeveloped, the farmers are at a low technical level, and it is planned to concentrate on beef production Intensive dairy production must be localized in the immediate vicinity of large centres of population, such as Tunis, Bizerta, Sousse, Sfax, etc Elsewhere, dairy animals will be bred in a semi-extensive way, crossing Brown Atlas with Tarentaise and Montbeliard cattle

TABLE 18

Tunisia. Climatic records for two stations in Tunis milk procurement area

Items

(a) = mean maximum temperatures (°C.)
(b) = mean minimum temperatures (°C.)
(c) = mean temperature (°C.)
(d) = mean rainfall (mm.)

TUNIS-AOUINA

Record period 1924–50. Altitude 3 m. Latitude 36°51′N. Longitude 10°15′E.

Item	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
(a)	14·7	15·6	17·6	20·5	24·0	28·7	31·5	31·7	29·3	24·7	20·3	15·9	
(b)	7·3	7·8	9·1	11·1	14·2	18·3	20·4	21·2	20·0	16·2	10·7	7·5	
(c)	11·0	11·7	13·3	15·8	19·0	23·5	25·8	26·4	24·5	20·4	16·1	12·2	
(d)	67	49	38	31	19	6	1	9	33	42	48	72	415*

MEDJEZ EL BAB

Record period 1901–50. Altitude 54 m. Latitude 36°39′. Longitude 9°37′E.

Item	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
(a)	14·5	15·6	18·9	22·5	26·5	33·5	34·9	34·1	30·5	25·6	19·5	15·2	
(b)	5·0	5·5	6·9	9·2	12·8	17·0	18·8	19·1	18·3	14·1	9·7	6·4	
(c)	9·5	10·5	12·9	15·9	19·7	25·3	26·9	26·6	24·4	19·9	14·6	10·8	
(d)	63	50	45	35	26	14	4	7	31	37	40	55	408

* The Vernet and Gaussen map gives 440 mm. for Tunis.

The Mission concludes that it is not possible and never will be possible to produce cow milk at average world prices This is particularly so in the Centre and South In the North, there are certain regions which could well be developed for milk production Much of the area is at present devoted to a cereal monoculture governed by export markets and a characteristic agrarian structure In the new irrigated project of the lower Medjerda valley the formation of co-operatives and the introduction of new rotations is considered to be particularly suitable for the development of a dairy industry

It is necessary to apply the agricultural criteria in a more precise and critical manner The chief areas of *potential fodder production* are the fallow lands in the cereal monoculture, and the irrigated land of the lower Medjerda It is necessary to map the 900,000 hectares of fallow on a rainfall basis, since it is this that governs the extent to which it is possible to break this age-old system by the introduction of fodder crops

The new schemes for rotations in relation to rainfall have been defined as follows in the 10 year development plan Le Houerou([96]) does not fully accept these schemes, considering that there is not enough fodder in (*a*) and (*b*), nor enough cultivated fallow in (*b*) and (*c*) The proportions of the area north of the line Hammamet–Le Kef in the different rainfall regimes are, according to the Vernet and Gaussen rainfall map

	Per cent
Below 400 mm	10
From 400 to 500 mm	60 to 70
More than 500 mm	20 to 30

(*a*) More than 500 mm rainfall
Wheat, barley or oats/fodder or hoed (sarclé) legume crops, e g horsebeans, chickpeas, peas, etc

(*b*) From 400 to 500 mm
Wheat, barley, oats or fodder/cultivated fallow or hoed legumes

(*c*) From 350 to 400 mm
Same as (*b*)

(*d*) Less than 350 mm.
Wheat or barley/cultivated fallow

The following five-year rotation, therefore, has also been recommended for the zone below 400 mm wheat/2 year temporary pasture/wheat/worked fallow The seeds mixture for the temporary pasture may be sown in the cereal crop in the spring, so that it may become established at the late April/May rains and recommence active growth with the first rains of September

If the fallow lands could be mapped, we would have a good idea of the potential area per annum of cultivated fodder crops. The fodder acreage could be one-half or one-third of the total cultivated area in rainfall zone (*a*), one-quarter of the total cultivated area in zone (*b*), and two-fifths of the cultivated area in zones (*c*) and (*d*). Taking these theoretical figures for acreages of cultivated fodders (which would not by any means be easy to achieve), and calculating the average annual yield of green and dry matter from the annual and perennial fodder and pasture plants that are adopted, it would be possible to estimate the total number of livestock (for milk, rearing, etc.) that could be maintained. One may find the proportion within that total livestock figure that would be represented by cows in milk. In order to make fodder production economic and sufficiently competitive with other crops, it would be necessary to have cows with a milk yield per lactation or per year characteristic of European breeds.

The project for the lower Medjerda valley is planned to embrace ultimately some 30,000 hectares, but development has slowed down at the 10,000 hectare level until the problems related to the salinity of the irrigation water have been solved. It seems feasible to consider that fodder crops will be grown only under natural rainfed conditions during the winter season. The most that may be hoped for is that annual fodder crops may be grown on one-fifth to one-quarter of the area of 10,000 hectares, namely 2,000 to 2,500 hectares.

No matter how good is the fodder that is produced, it will be essential to feed high-protein concentrates to the high-producing European breeds that are to be maintained under good management on the best lands. At present it does not appear that many of the essential ingredients are produced within the country (apart from a small increase in the cotton acreage). The supplementary feeds being considered are imported linseed cake, and home-grown horsebeans and field peas. The proposal of the FAO/UNICEF Mission to set up a centre for the industrial production and conservation of fodder, including lucerne meal, would seem to be a doubtful practical and economic proposition—much better for each farmer to plan his own fodder conservation on the basis of the conditions and particularly the variability of his own environment. In order to economize on imported concentrates, it would appear to be desirable to base the higher-producing more efficient dairy industry on a large number of animals of average production rather than on a smaller number of high-producing animals that need large amounts of concentrates for the greater part of the production ration.

The number of animals of different types in Tunisia is given in Table 19 for the present time, 1964 and 1970. The imports of dairy products are given in Table 20 for the period 1955–61. To these should be added American gifts of powdered milk to the amounts (in metric tons for the years 1957–60 inclusive), of 1,209, 806, 467 and 959 respectively. The imports of butter and cheese in 1960 and 1961 represent the total production from about 7,200 and 8,000 cows in milk yielding 3,500 litres per year at 3·5 per cent fat.

TABLE 19

Tunisia Structure and composition of the livestock population

Type of animal	1962	1964	1971
Dairy cattle	500	5,000	25,000
Dual purpose cattle	—	130,000	81,000
Beef cattle	—	—	50,000
Unimproved	280,500	80,000	—
Working oxen	100,000	100,000	20,000
Horses, mules, donkeys	125,000	125,000	100,000
Sheep	1,030,000	1,900,000	2,320,000
Goats	1,000,000	600 000	600,000
Poultry	3,000,000	4,000,000	6,000,000

TABLE 20

Tunisia Imports of Dairy Products

	1960 Metric tons	Expressed as kg milk	1961 Metric tons	Expressed as kg. milk
Butter	615 3	14,767,200	693·0	16,632,000
Cheese	1,035 6	10,356,000	1,143 4	11,434,000

In conclusion it should be stated that it is unwise to base a review of the dairy potential upon considerations of a broad national or even regional basis It is first necessary to know the precise location of existing or planned milk plants, collection points and chilling centres, and then to map the procurement areas with the radius acceptable for economic collection All further agricultural calculations and extension efforts should be concentrated within these areas, as it is only there that one can talk to the farmers in the language they know, the economic return in litres and dinars per hectare in relation to those obtained from other types of farming

GREECE

The various types of degraded vegetation in Greece that go under the name of natural hill and mountain pastures are suitable only for sheep and goats. Adjacent to many villages is an area of grass/legume pasture on land that is generally too wet or otherwise unsuitable for cultivation. On these village pastures the pressure of stock is so great that they can be regarded as providing only relatively poor grazing for dry cows and young dairy stock on a rather low level of nutrition. Again we find that productive dairy animals must rely on cultivated fodders or perhaps sown pasture areas on dry and irrigated land, integrated into the cropping system.

The farmers of Greece have long practised the cereal/fallow system of monoculture characteristic of the Mediterranean region. It is known that legumes for grain or fodder may be grown in the fallow year wherever the annual winter rainfall is favourable. A whole range of annual legumes is available, from peas at the higher rainfall limits to *Ervum lens* for grain at the lower. Lucerne(114) and berseem grow well under irrigation. Some years ago it was thought that there was a marked trend towards these and other types of improved rotations, but this became replaced by the continuous cultivation of wheat combined with applications of fertilizers to make up for the absence of the fallow year.

It is obvious that what is needed is an economic return from the legume fodder year, and it is this incentive that dairy development can provide. It is Government policy to promote a change in cropping, particularly from wheat which in recent years has covered more than 40 per cent of the land under annual crops, to a more diversified mixed farming system incorporating fodder crops and more livestock. Intensification of production in the plains depends primarily on a large expansion of the area under irrigation. Areas with experience in livestock production such as Thessaly, Thrace and Macedonia are selected for development.

Subsidies are given for the cultivation of fodder crops, particularly legumes. The importation of improved cattle has progressed at the rate of about 2,000 per year, partly for production, partly for crossing with the low-yielding indigenous cattle.

The FAO/UNICEF Mission that investigated dairy development in June/July 1960 reported that the industry was being given an important place in the plans of the Ministry of Agriculture.(45) After completion of the general scheme, the Ministry negotiates with co-operatives of live-

stock farmers regarding the establishment of a milk plant and the Agricultural Bank studies the project with regard to supply, consumption and other factors During the current 10-year period, 1960–70, nineteen milk plants are tentatively planned with the small capacity of 5,000 to 10,000 litres per day. The FAO/UNICEF Mission were particularly concerned with Patras, Drama-Kavalla, Serres and Salonika, with daily throughputs of 30,000 to 50,000 litres per day.

In general, it was found that the farmers are well able to carry out the techniques of a traditional form of animal husbandry, but that there was:

(a) a tendency for uncontrolled cross-breeding;
(b) a need to modify current management practices, particularly with regard to better housing or the construction of yards; and
(c) an apparent tendency to feed for cheapness rather than production, owing to the limited market for milk

There is a need to achieve efficient conversion of feeds and fodders into milk and meat through a correlation between production and feed intake, and to apply the milk recording scheme established at Drama to the procurement areas of all existing and proposed milk plants The arrangement whereby concentrate feeds are supplied through the co-operatives or the Agricultural Bank is highly commendable and should be extended to roughages such as lucerne hay so that the farmers may benefit from the lower prices resulting from bulk purchase and marketing

TABLE 21

Greece Cows, milk yields and milk production
(Cow milk represents one third of total production)

Category of cows	Number	Milk yield per head kg.	Milk production tons
Indigenous	234,700	460	107,900
Improved indigenous	73,300	940	68,900
Imported of improved breeds	134,100	2,750	93,700

The FAO/UNICEF report on Greece analyses the situation at each of the four centres individually and provides much of the data upon which an assessment of actual and potential production might be made Possibly after the incentive has been provided by the establishment of milk plants, it will be found that the chief limiting factor to a rapid

increase in production will be the small average size of farm holdings (3 hectares) and their fragmented nature, a difficult size and type of unit in which to practise alternate husbandry.

TURKEY

In its control of the agricultural policy and production, the Government has in the past given more stimulus to crop than to livestock production, because crops are the chief source of export earnings and a greater production of some crops such as sugar has led to savings in import expenditures. An expansion of dairying would bring little benefit in these directions because most of any additional output would go into domestic consumption. The FAO Background Report on economic aspects of dairying[39] makes the point that priority to dairying would have to be based on the argument that general benefits would be expected from the development of a more balanced and efficient agriculture, the raising of standards of human nutrition and consequently the stimulation of national output of goods and services generally.

Cows and buffaloes together produce about 65 per cent of the total milk supply, but milk yields per cow per annum have remained very low at 500 kg. By 1975, it is planned that the numbers of livestock will have reached a stable figure, apart from the nine million head of ordinary goats, which it is planned to reduce. The trend has been in the direction of increase of cattle numbers rather than towards higher average yields per animal. This leads to even greater competition for limited feed resources and overgrazing of the natural grasslands, so that the problem of underfeeding increases and the low yields become still lower.

The objectives should be to improve the incentives offered to farmers, to provide the required feed and fodder basis for greater production and to improve the efficiency of that production. Much of the oilcake that is produced in Turkey is exported for foreign exchange (Table 22). Turkish farmers cannot obtain concentrates at reasonable prices, and therefore cannot afford to feed them to their low-production animals. If more feeding stuffs could be made available locally through co-operatives or similar sources, there would be an incentive to keep better cows.

Economic feeding demands, however, that the main basis of nutrition should be green and conserved fodder plants grown in rotation with the major food and cash crops. For this purpose we must distinguish between the climate of the eastern mountainous region (Erzurum, Kars),

TABLE 22

Turkey Exports of Fodder (in thousand tons)

	1957	1958	1959	1960	1961
Oilseed cake and meal	58·4	113·8	134·7	137·1	142·9
Brans	1·0	10·1	45·5	38·6	23·1

the continental 'Irano-Turanian' climate of the Anatolian plateau (Ankara) and the 'Mediterranean' climate of the western and coastal regions (Istanbul and Izmir) comparable to the conditions in the Greek sites discussed above

The distribution of milk production in these three ecological regions and the Black Sea Coast (Mediterranean environment) is roughly as follows

	Per cent
Eastern Mountains	35·4
Anatolian Plateau	24·1
Western and southern coastal	22·2
Black Sea Coast	18·3

It has been suggested(42) that, when economic and practicable, the grazing of improved pastures should be adopted as part of any development programme for increasing milk yields, that more oats should be fed as straw in winter to release wheat straw for bedding, and that more cotton seed should be fed to buffaloes where they represent a substantial proportion of the milch animals

As far as sown dryland pastures in the plateau are concerned, the severe continental climatic conditions would limit these to the type sown in the western range of the United States of America It is understood that successful pasture sowings have been made in the central part of Anatolia, including Konya area, with species of *Agropyron*, *Bromus*, *Festuca*, alfalfa, sainfoin, etc

The Government has now started feeding demonstrations on private farms in twenty provinces The Government provides the concentrate feeds, the farmers provide the lucerne or sainfoin hay or other roughages Feeding rations are devised for the indigenous Turkish breeds of cattle (1,700 animals in all), which are found to give three times the average yield of milk under this improved standard of nutrition An economic factor is the high cost of transport of concentrate from the

TABLE 23

Turkey Climate records for Ankara

Items

(a) = mean temperature daily (°C)
(b) = mean maximum temperatures (°C)
(c) = mean minimum temperatures (°C)
(d) = mean number of days with minimum temperature below 0°C
(e) = mean relative humidity in percentage at 07 00 hours
(f) = mean relative humidity in percentage at 14 00 hours
(g) = mean relative humidity in percentage (daily)
(h) = mean total precipitation in mm (daily)
(i) = mean number of days with precipitation 0 1mm and above
(j) = mean temperature of soil at 5 cm depth (°C)

Record period 1926–50 Altitude 894 m Longitude 32°53′E Latitude 39°57′N

Item	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov.	Dec	Year
(a)	3 4	5 0	10 6	17 6	22 7	26 7	30 0	30 3	25 7	20 3	13 4	6 1	
(b)	−4 5	−3 6	−0 6	4 6	9 5	12 4	15 1	15 3	11 2	6 6	2 5	−1 3	
(c)	15 0	17 6	26 6	31 6	34 4	36 4	37 5	38 0	35 6	31 9	25 3	17 2	
(d)	24 2	19 6	15 4	4 2	—	—	—	—	0 1	2 0	8 0	17 4	
(e)	85	83	79	72	69	63	56	55	63	74	85	87	
(f)	71	65	51	40	39	33	28	26	31	39	54	70	
(g)	79	76	63	57	56	50	42	41	46	57	71	80	
(h)	32 4	31 2	32 5	31 3	48 5	25 7	12 5	10 1	15 3	22 5	30 8	48 2	340 7
(i)	12 3	11 8	9 9	9 7	11 2	7 6	8 1	1 8	4 4	6 9	7 5	12 6	
(j)	0 6	1 9	6 1	13 1	19 5	24 3	28 1	27 9	22 2	14 7	8 2	2 9	

TABLE 24

Turkey Climate records for Istanbul Yesilkoy

Record period 1937–50 Altitude 1,715 m Longitude 28°49 E Latitude 40°58 N
(For key see Table 23)

Item	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
(a)	6 2	4 2	5 9	10 7	16 3	20 3	23 1	22 6	19 0	15·0	11·0	7 8	
(b)	9 3	7 8	9 8	16·0	21 5	25 2	28 5	28 2	24 5	20 0	15 1	11 0	
(c)	2 9	0 8	2·4	6 1	11 6	15 3	17 2	17 2	14 6	11 1	7 5	4 9	
(d)	8 3	10 5	7·0	1 3	—	—	—	—	—	—	1 3	4 5	
(e)	85	84	85	86	80	80	76	80	84	87	85	86	
(f)	75	72	70	66	66	66	60	53	59	65	68	76	
(g)	81	80	80	79	79	79	87	71	75	79	79	82	
(h)	68 1	62 1	76 0	56 7	20 0	44 2	17·4	23 5	54 7	43 0	63 2	10 6	635 5
(i)	15 3	14 1	15 3	10 6	6 7	6 7	2 6	3·4	5 6	8 3	10 4	19 6	
(j)	3 6	4 9	7 7	13·4	19 9	14 5	26 2	25·4	21 7	16 0	11 5	7 6	

areas of production in the winter rainfall environment of the south and west to the Plateaux and eastern mountainous regions.

The Government has approved a dairy production law, which allows for the establishment of the new milk plants (with international and bilateral assistance) which are essential if the necessary incentive of regular and reliable markets is to be provided. To support this effort, eight feed-mixing plants have been established in Izmir, Bandirma, Ankara, Erzurum, Konya and other centres.

The period covered by the present Five-Year Plan of the Government of Turkey is 1963–7. The budget for investment in agricultural development for this period is 11·3 milliard Turkish lire, excluding 123·8 million T.L. for agricultural education. The percentage breakdown of the larger sum is as follows:

	Per cent
Irrigation	45·3
Agricultural equipment	15·0
Land improvement	6·1
Forestry	8·8
Livestock	4·2
Fisheries	2·6
Other purposes	18·0

The third item, land improvement, includes among other things, range and fodder development, soil conservation, drainage, etc., amounting to 1·5 per cent of the total.

By 1967 it is planned that the eight feed-mixing plants in operation in 1963 shall be increased to ten, and that the annual production will increase from 18,000 to 26,000 tons in 1963 to 88,000 to 150,000 tons in 1967, part still for export, part for domestic consumption depending upon the demand from the livestock industry. The total production of concentrates (cakes, grains and bran) was 3,600,000 tons in 1962; this is planned to increase to 6,167,000 tons by 1967. It is at the same time planned to reduce the area of summer fallow and to grow more legumes in rotation. To support this and pasture development generally, there has been a great increase in the amount of seed produced of lucerne, korunga (sainfoin) and other legumes and grasses, from 75 tons in 1953, to 1,300 tons in 1963, with a target of 3,550 tons in 1967. The ten centres in 1963 for the multiplication of original seed will increase to twenty-five by the end of the Plan period; farmers will provide further multiplication of certified seed. The amounts of fertilizers used on pastures and

fodder crops will increase from 10,600 tons in 1963 to 97,500 tons in 1967, there will be an attempt to assist farmers by the granting of subsidies Some 150 green fodder silos were built in 1963 under extension projects, and 78 research projects on range pastures and fodder crops have been conducted Everything possible is, therefore, being done to improve the feed and fodder basis of the livestock industry

LEBANON

Those areas that supply liquid milk to Beirut present a condition to which other less developed areas appear to be progressing, namely, a population of high producing cows, dependent largely upon concentrates and other purchased feed because cultivated fodder crops cannot compete, in the farmers' opinion, with the high value cash crops of the area The cultivators keep the cattle to provide manure for their vegetable and fruit crops (the manure being a highly concentrated product with a minimum of straw, selling for 1 5 to 2 piastres per kg), grow little or no fodder crops, and sometimes have a little spring grass collected from odd corners Apart from this they use maize silage (sold at 4 piastres per kg. delivered) and concentrates

Although there is a marked scarcity of fresh milk in the centres of population, the milk producers do not have a reliable market, and many of them have a tendency to reduce their cattle numbers to a minimum. This paradoxical situation is due to deficiencies in the system of marketing, to adulteration and to competition from imported powdered milk of 2 5 per cent fat content.

The FAO/UNICEF Mission that visited Lebanon in February/March 1962, found it to be extremely difficult to arrive at even an approximate estimate of the bovine population ([57]) It is not considered an exaggeration to assume that there are 30 000 milch cows in the Lebanon The Mission calculates a total production of 100,000 metric tons of milk per annum at 3,500 kg per animal, but this does not make allowance for dry cows and young stock. The dairy herds are based on imported Holsteins from the Netherlands, crossed in varying degrees with the local red Baladi or with the Damascus It is apparently rare to find an animal that yields less per lactation of 8 or 10 months than 4,000 kg. milk (see Table 10) It is considered regrettable that the local Baladi and Damascus races are tending to disappear except in the far north of Lebanon, particularly as these well adapted animals will be required for further crossings.

UNITED ARAB REPUBLIC

There are considerable seasonal variations in the supply of milk in the UAR, due, primarily, to the fact that berseem and lucerne are available only in the season of winter rainfall. During the agricultural reform in the UAR, large farms were divided into units with a maximum area of 100 acres, and this has contributed to a decline in total crop and animal production. Later the Government stimulated an increase of co-operative management among producers, with the result that there are signs of an increase in agricultural production. Any increase in milk production, however, is seriously limited, due to sharp competition with the meat industry. Increased purchasing power of the worker which followed the industrialization of the area between Cairo and Alexandria has led to a great increase in the demand for meat, the price of which has doubled or quadrupled. Thus a shift from milk to meat production has taken place. An attempt to encourage milk production by raising the price paid to the producer, with a seasonal fluctuation, has not yet increased production sufficiently to meet the continuously growing demand of the urban populations. The retail price of pasteurized milk in Cairo and Alexandria has not changed since 1956.

SYRIA

The semi-arid zone of dryland farming in northern Syria, in which is the city of Aleppo, is, according to the FAO/UNESCO/WMO agroclimatology study,([56]) bounded on the north by the more humid foothill zone (500 to 800 m. elevation), and on the south by the arid steppes of Syria, in which is the city of Damascus. The semi-arid zone around Aleppo has a continental climate (cold winter and hot summer); the highest monthly precipitation falls in December, but the total amount of rainfall fluctuates widely from year to year. The temperatures of the moderate winters remain at a mean minimum below 3° C. for two to three months; from March onwards the rise in mean temperatures is very rapid (more than 4·5° C. per month). Mean annual precipitation (at Aleppo = 400 mm.) is variable (250 to 500 mm.); the inter-annual variability of precipitation is high in the vicinity of the arid zone and falls rapidly as one approaches the mountains. The regular rainy season at Aleppo begins in late October/early November, and finishes at the end of April. The calculated annual evapotranspiration (ETP) values gener-

ally lie between 1,300 and 1,450 mm Precipitation can cover the theoretical need of ETP from the beginning of November to the end of April, for all rain falling in winter is stored and can be used in spring (although part of the precipitation is lost through run off, due to ploughing up and down the slope and to the land tenure traditions whereby farmers own long narrow strips of land that extend from the valley to the crest of the hill)

The mean maximum temperature of the summer season of 200 to 250 days (sums of temperature exceeding 15° C range from 1,500 to 2,400° C —lower in Aleppo than in the east) rise above 35° C for two to four months The relative air humidity exceeds 35 per cent around Aleppo The ETP values for July in Aleppo are 240 mm. The western part of the Fertile Crescent in which Aleppo is situated has a climate similar to that of the Zagros valleys, south-eastern Turkey, Cyprus and the San Joaquin Valley in California

The soils in the Aleppo area belong to the Red Mediterranean soil group or Terra Rossa Soils of the Steppe type occur farther east. The Terra Rossa soils are not very subject to wind erosion when ploughed, soils of the Steppe type (Jezira area) are subject to wind erosion

Agriculture is based on the winter cereal/fallow cropping system in localities where the mean precipitation is over 240 to 270 mm The Syrian Government has passed a law prohibiting ploughing of new land in all areas receiving less than an average of 200 mm. Maps were prepared and distributed to Government offices concerned, showing the line beyond which ploughing should not be permitted Much range land has been destroyed by those who gamble on the rain by cultivating submarginal land Winter- and spring sown grain legumes are introduced into the rotation in the more humid areas

Spring/summer dryland crops such as cotton and water melons are grown in the Aleppo area if spring rains are abundant in the fallow year The land is clean fallowed in the winter, and if moisture conditions in spring are favourable, one of these crops is planted Irrigation in the Aleppo milk procurement area is limited, and the cow population in and around the city is small To provide for the planned capacity of 20,000 litres per day for the Government/UNICEF dairy factory, it will be necessary to develop dairy farming in irrigated areas at a greater distance from the city, and to transport the milk from chilling centres Irrigated fodder crops would include lucerne, maize, sorghum, Sudan grass, annual winter cereal/legume mixtures, irrigated pastures (on shallow soils), annual winter fodder legumes may be included in the

rotation on dryland areas, receiving over 400 mm. average rainfall for hay or spring grazing, but yields are too low to form a basis for dairy farming (about 5 tons green matter per hectare).

The characteristics of the climate around Damascus also limit the possible development of a profitable dairy industry to the irrigated lands. The FAO/UNESCO/WMO agroclimatology survey classifies the area within the arid zones of the Syrian steppe. The region is characterized by an arid and continental climate, generally moderate winters, and summers varying from very hot to extremely hot. During the winters, the mean minimum temperatures remain below 3° C. for 1·5 to 3 months, below 10° C. for 2 to 3 months, and rise very rapidly in spring (about 5° C. per month). The mean annual precipitation generally lies between 100 and 250 mm. The regular rainy season is from early December to late March. The relative air humidity is less than 75 per cent during the winter months and falls rapidly from March onwards. The annual evapotranspiration (ETP) values are 1,400 to 1,700 mm., but monthly precipitation never covers ETP.

The summer season begins towards mid-March and lasts more than 200 days until early November. The elevation being about 700 m., the maximum temperatures in Damascus are generally below 35° C. The relative air humidity is below 20 per cent at midday for more than 5 months. Areas with relatively similar climates are found in the southern part of the San Joaquin Valley in California for the whole year, while the summer climate is to be found on the high plateaux of Iran (Yazd).

According to the Statistical Abstracts for Syria of 1958, the irrigated areas comprise 600,000 hectares, of which 98,000 hectares are in the Mohafaza of Damascus and 145,000 hectares in the Mohafaza of Aleppo. Assuming that one-quarter or one-fifth of these areas might ultimately be devoted to fodder crops, these fed in the green or conserved state plus the arable crop residues should provide a good basis for an efficient and economic dairy industry. The present standards of animal nutrition and management in these irrigated areas are extremely low, and there is the problem of bilharzia (Research at the Laboratoire National de l'Elevage at Dakar has shown that there certainly exists a relationship between human bilharziosis (*Schistosomum curasonni*) and bovine bilharziosis, at least in Senegal, and that the intermediate hosts in stagnant water may be destroyed with chemical products of the zirame type.) One would hope that the high-quality fodders combined with residues of arable crops would provide all the maintenance rations and the initial kilogrammes of milk production, over and above which

it would be necessary to feed concentrates, although here again Syria exports its cotton seed and cereals for foreign exchange while its animals starve

A certain amount of agricultural by-products is fed to dairy cattle, especially in the Damascus oasis (irrigated area around Damascus) Concentrates used are barley, grain legumes (*Vicia sativa, Lathyrus sativus, Ervum ervilia*), cotton seed cake, beet pulp, wheat bran Green fodder is given to dairy cows in this area in late autumn–early winter (*Vicia sativa* mainly), spring (*Trifolium alexandrinum, Medicago sativa*) and summer (*Medicago sativa, Zea mays*) In the late spring and early summer, green fodder is even wasted on some farms, conservation into hay of part of the excess green fodder in this period of peak production would be highly recommended, the hay to be used in periods of shortage of green feed, in calf rearing and to help in curing digestive disturbances Fodder crops in this area of intensive agriculture are grown mostly under orchards, in rotation with vegetables, hemp and wheat. Fodder crops are often grazed, the animals being tethered and thereby forced to graze the succulent parts, stems and weeds Productivity of the leguminous fodder crops could be increased by the use of phosphatic fertilizers Although farmers generally feed some concentrate or straw before the animals are turned out to graze on leguminous fodder crops, cases of bloat are quite frequent, often resulting in the loss of the animal.

Although fodder crops are grown and concentrates fed in the Damascus area, information needs to be given to the farmers on the utilization of these feeds in a well balanced ration based on needs and production levels of the cows Poor management is reflected especially in the high rate of mortality among new born calves, which is estimated to be between 20 and 50 per cent, a major reason is malnutrition, and secondly the practice of not separating the calves from the mothers at birth (salmonellosis infection) ([61]) Progress towards more efficient and economic production may be achieved when farmers become convinced of the merits of growing green fodder crops They will not regard fodder crops as competitive with their food and cash crops in economic return per hectare until they have animals with a level of production capable of giving a good return on the investment involved in the practice of alternate husbandry or mixed farming.

The production aspects of dairy development have been stated by A. E. Charpentier([51]), his summary of the present position and possible trends is quoted.

'The development of agriculture in the Syrian Region has been

remarkable during the last ten years, especially with regard to the production of cotton and sugar beets. The more intensive the cultivation of crops becomes, the more attention must be paid to soil conservation and maintenance. In order to secure good yields also in the future, rotation of crops with, for example, legumes and cultivated pastures has to be practised by farmers. The farmer has then to consider what kind of livestock he would prefer for utilizing the foods. He may favour the idea of keeping dairy cows because by selling milk he would receive cash money regularly throughout the year and not only, for example, at the time of harvest. Thus, he and his family's everyday life would become more comfortable and a basis would exist for the raising of the living standard of the family.

'The fundamental purpose of livestock on farms is generally considered as the transformation of plant products into more desirable forms of food for human consumption. That type of livestock which can utilize the largest yielding crops and return the greatest proportion of the nutrients in the form of human food is the most efficient. The dairy cow has proved to be the most efficient farm animal. In the first place, cows excel in the use of roughage, especially in the form of alfalfa, clover and corn silage, which yield larger amounts of digestible nutrients per hectare than concentrated feeds such as wheat, barley and oats. In the second place, milk produced from 100 kg. of digestible nutrients contains more edible food solids than any other livestock product. Further, the dairy cow produces during its lifetime up to ten calves, and when finally slaughtered it represents an additional value in meat and by-products.

'The direct usefulness of dairy cattle in maintaining soil fertility is also very considerable. An average dairy cow produces about 10–15 tons of manure a year, which contains a great deal of the nitrogen, phosphorus and potassium from the feeds.

'The more intensive agriculture becomes, the more economical will be the keeping of dairy cows in comparison to the keeping of other kinds of livestock. This is the case on an increasing number of farms, especially in the western parts of the country. In the semi-desert area, however, sheep will prevail until irrigation is started and cultivation improved. In fact, it has been recommended recently that in this area on the present degraded pastures the density of animals should be considerably reduced. Lack of sufficient precipitation prevents the development of pastures for cattle in the major part of the country, excluding the relatively narrow coastal area and the northern provinces.

'To encourage farmers of the western part of the country to improve dairying, it is necessary to facilitate the obtaining of long-term credits for farm improvement and purchase of cattle and to provide technical assistance through adequately trained government extension services.

'The question as to which foreign breed would be suitable for introduction into the Syrian Region has aroused much interest However, as the climatic conditions in Syria are by no means unusually severe, the problem is not so much the question of the breed but rather that of how to improve management, feeding and animal disease control, the present status of which does not give even the indigenous breeds a chance to show what they are worth It will be advantageous to import foreign breeds, for example, Red Danish, Friesian or Brown Swiss, in order to improve local cattle, excluding the Damascus breed, through cross-breeding, but success can be achieved in this connection only if proper management is introduced from the beginning

'The Damascus cow has proved to be an excellent milking animal even under prevailing management conditions which are often adverse. Unfortunately there are today only a few thousand animals left which can be considered pure Damascus Everything possible should therefore be done to preserve this well-adapted breed and to improve it through selection With production control combined with extension work started on key farms as planned, it would become possible within a few years to obtain sufficient basic knowledge regarding the relation between good care and feeding on one side and growth, development of structure and production on the other, and to find suitable specimens, especially bulls, for the further development of this breed

'If the production of cow milk could be gradually increased threefold from what it is now during the next five years, and sixfold within the period up to 1980 when it is estimated that the population of the Syrian Region will have reached six million, a basis for more favorable consumption levels would exist This would mean that by 1965 the daily average production of cow milk would be about 1 million kg , and by 1980 about 2 million kg The first quantity could be obtained from 200,000 cows producing 5 kg of milk per day as an average, the second from 250,000 cows with an average daily production of 8 kg At present only about 100,000 head are considered dairy cows, but the total number of cows is about 300,000 Thus in order to reach the quantities in question, it would not be necessary to increase the present number of cows but to improve the production of individual animals to the above-mentioned levels This principle should rule every producer who wishes

to improve the economy of his farm, providing he is prepared to introduce better breeding and feeding methods, take better care especially of calves and heifers, and practise proper milk hygiene. It is evident, as mentioned before, that farmers will pay much more attention to these problems once a safe market for milk with reasonable prices becomes available. The necessity of clean milk handling will also be remembered when payment for milk is based on quality.'

At present, part of the milk and milk-products consumed in the country is derived from imported powdered milk. For example, it is claimed that the private dairy pasteurization plant uses up to 50 per cent of powdered milk in its products. Through better feeding and management, selective breeding of the good types and upgrading of the Damascus breed, and the use of foreign breeds, the productivity of the dairy farms and mixed farms could be increased and the price of milk reduced. In the Damascus milk procurement area, there are about 10,000 dairy cows (about 6,000 milking cows, 2,000 to 3,000 heifers and 1,000 to 2,000 calves). Of these, 2,000 to 3,000 are considered to be pure Damascus, the remainder being foreign breeds, crossbreds and nondescript.

In the plans for the agricultural utilization of the 200,000 hectares which will be irrigated in the first phase of the Euphrates irrigation project, consideration is given to mixed farming in at least part of the area. Sheep would be introduced under this mixed farming concept (for ghee, meat) and in a later stage, dairy cattle may possibly be introduced on a gradually increasing scale.

JORDAN

A study of dairying and dairy development in Jordan was made in 1958–9.([46]) E. Siegenthaler states that the livestock population in 1957 was: cattle, 64,000; goats, 540,000; sheep, 453,000; but that the numbers of sheep and goats in particular were seriously affected by seasonal droughts in the desert areas. It is true that the Bedouin are more interested in large flocks than well-fed ones. Cattle in Jordan are of the native Baladi and Shamiyeh (Damascus) breeds, and there are also imported Holstein animals and various random crossbreds. Apart from a few well-managed dairy farms with high producing cows, the average milk yield of cows is about 1·5 to 2 litres per day for a lactation of 6 to 8 months. Exact figures of local production of milk and dairy products are not available. It is estimated that the annual production of milk is about 35,000 to 40,000 tons, about 65 per cent of it coming from goats

and sheep It is concluded that Jordan cannot expect to achieve self-sufficiency in milk and milk products A certain amount of progress has been made through the activities of the Arab Development Society In 1961, 26 Friesian heifers were introduced into the Society's Experimental Farm near Jericho, and numbers have now increased to 170 head of cattle The land on this farm and on that of private farmers in other parts of Jordan Valley is now being grown to lucerne as fodder for dairy cattle in place of the former and now less economic crops of vegetables On the Experimental Farm at Jericho, the animals are fed in yards and no animal has so far been lost through illness There are now some thousands of Friesians of Dutch or English origin in Jordan, presumably producing sufficient milk for the higher income groups

Imports for the years 1957–8 were as follows

	1957	*1958*
	Tons	
Preserved milk and cream	2,549	1,790
Fresh salted butter	2,099	1,584
Melted butter or butter oil	178	352
Cheese	224	280

Seasonal fluctuations in production are very pronounced since most of the milk comes from sheep and goats These animals are in milk for only about three months each year The prices of milk and milk products therefore fluctuate widely

IRAQ

Baghdad lies in the arid zone of Central Iraq, an area represented by an extensive alluvial plain with a gentle slope, at an altitude of less than 200 m. above sea level Cropped areas are situated on both sides of the Rivers Tigris and Euphrates According to the FAO/UNESCO/WMO agroclimatology study,(56) the climate is arid and highly continental, with mild winters and extremely hot summers The mean minimum temperature in January is about 12° C , the mean temperatures higher than 10° C. rise rapidly from January onwards (more than 3° C per month) and from March onwards increase more or less regularly by about 5° C per month The weak and variable mean annual precipitation seldom exceeds 200 mm with an inter annual variability of 52 per cent. The regular rainy season begins in late December and continues for 90 to 130 days until March The relative air humidity remains above

50 per cent from April to May and does not generally fall below 30 per cent during this period. The evapotranspiration (ETP) values are from 1,700 to 2,000 mm. and at Baghdad reach 280 mm. in July. There is considerable risk of hot winds and dust storms, particularly from February to May, and in July; at Baghdad this risk appears to be greater in winter (two days per month). The summer season begins in the second half of February or early March and ends in early December (250 to 300 days). There are 150 days with mean maximum temperatures exceeding 35° C. and more than 100 days when these temperatures exceed 40° C. The sum of temperatures above 15° C. for the season is more than 3,000° C.

Agriculture is still of the extensive type, but dependent upon irrigation. Ninety per cent of the sown lands is under winter cereals (wheat and barley) and some legumes (beans); 10 per cent of the total area is sown to summer crops such as cotton, sorghum and rice. Irrigated date palms are important, while fruit trees and crops of lucerne are found in certain areas. The very high summer temperatures militate against the cultivation of annual species and call for intensive irrigation, thus creating major problems of drainage and salinity. Large parts of the lower Mesopotamian plain have become saline during the millenia since the practice of irrigation began, due to high evapotranspiration in the summer and a high groundwater table. Studies on drainage have been undertaken and completed for certain areas, but the execution of drainage works on a large scale is still lacking. Following the completion of two dams in tributaries of the Tigris River, more irrigation water is becoming available for summer crops in areas irrigated from the Tigris.

An expansion of the acreage annually under summer crops would have to be combined with the provision of adequate drainage in order to avoid further salinization of land which is at present still non-saline. The same may be said regarding possible intensification of cropping during the cool season. The widespread two-year cereal/fallow rotation could be replaced by a more intensive cropping pattern, introducing an annual winter fodder crop into the rotation. Such an intensification of irrigated winter cropping, whereby the fallow is at least partly abolished, would, however, hasten salinization unless an adequate drainage system is provided.([153])

The Meskawi variety of berseem (*Trifolium alexandrinum*) is well adapted as an annual winter legume to be grown in rotation with cereals in the irrigated areas of the Mesopotamian plain. Sowing would have to be done quite early (late September/early October) in order to have

one cut before the onset of cold weather in December Occasional light night frosts and cold weather may retard growth in January or February, but about five cuts yielding about 60 tons green matter per hectare can usually be obtained At present, there is only a limited acreage under this crop The area under lucerne (*Medicago sativa*) is relatively larger but its cultivation is restricted to the vicinity of the large centres of population, especially around Baghdad It is often grown under dates and in other orchards, not on heavy river basin soils but on lighter river levee soils As around Baghdad the crop has to compete with high-value crops such as vegetables, the green lucerne is sold for high prices in the market. Harvesting demands much labour, the crop is cut by sickle, tied in small bundles and sold per bundle In recent years, due to the completion of good trunk roads leading to the city, there is a tendency for its cultivation to extend farther away from Baghdad.

Lucerne is the main green fodder used for feeding of the cattle and buffaloes concentrated in and near Baghdad In spring, green barley is also cut and carted to the city, or the first growth of irrigated barley may be grazed, after which it is left to produce grain Under this system, fields of barley are rented to buffalo owners from around the city Occasionally barley fields may be used exclusively for grazing by dairy animals (cows and buffaloes) The early growth of irrigated wheat and barley may be grazed by sheep, especially when the rains in the range areas are late or fail Fallows are sometimes given one or more irrigations, and the spontaneous vegetation consisting mainly of annuals is grazed in the winter and early spring.

Apart from these occasional grazings, most dairy animals in the Baghdad area are kept in compounds and near the houses of the owners, and feed is carried to them Most owners of dairy animals do not themselves own land, green feed thus has to be purchased, or an occasional grazing in winter or spring taken on a rental basis The largest amounts of green feed are fed in spring, in summer the amounts given are less (mainly lucerne), and in autumn often no green feed is provided Cereal straw is the roughage, and concentrates consist of barley, bran, cotton seed cake, linseed and sesame seed meal, legume grains, and sometimes low-quality dates Successful experiments have been made at Abu Ghraib Experiment Station with the feeding of date by products in the rations of dairy cows, buffaloes and sheep Silage of various fodder crops has also been produced at this station, using soaked dates or date molasses as a preservative

The conservation of green fodder in the form of hay or silage will

have to be done on a much larger scale in order to provide a more balanced ration in late summer and autumn. Prices of green feed are relatively low in spring and higher later in the year, so that conservation would be an economic proposition. Moreover, hay would help in overcoming digestive disturbances and would be of value in calf-rearing.

The Dairy Administration made a reconnaissance survey of the cattle population in the Baghdad area in 1963, and collected the data given below. A detailed survey is being made by the Animal Husbandry Division of the Ministry of Agriculture.(1)

Cattle population in Baghdad milk procurement area	
Buffaloes	30,000
Cattle:	
Native (Jenubi)	2,000
Crossbred (Jenubi × Friesian, Jenubi × Ayrshire)	3,000
Milk yield per lactation (in kg.)	
Buffaloes	3,800
Native Jenubi	1,500
Crossbred	2,500

Percentage of local bovine population in milk at one time

In the Baghdad area, it is estimated that 70 to 90 per cent of the mature buffalo population is milking during the period from 1st August to 15th April. The peak of the dry season for buffaloes is in May and June, when the number of dry animals reaches 60 to 70 per cent of the adult buffalo population. The freshening of cattle is fairly well distributed throughout the year, with a slight increase in calving in the autumn and early spring months.

Age at first calving

Buffaloes	27 to 40 months (average 33)
Cattle	24 to 36 months (average 30)

Intervals between calvings

Buffaloes and cattle about 12 to 15 months.

Length of life and number of lactations

Buffaloes	12 to 15 years 8 to 13 lactations
Cows	8 years 5 to 6 lactations

Good feeding and management combined with good breeding could

give a yield of 6,000 kg. milk from buffaloes and 4,500 kg from cross-bred cows (1)

The Central Dairy Plant receives 20,000 litres of milk per day, increasing to 22,000 to 23,000 litres during the winter months A second factory at Abu Ghraib came into operation in 1965 to process.

(a) an additional 20,000 litres of milk for sterilized plain and flavoured milk, butter and cream,

(b) 5,000 litres for yoghurt production (seasonal summer),

(c) 10,000 litres for cheese production (seasonal winter),

(d) 5,000 litres for ice-cream (seasonal summer)

A factory to produce dry and condensed milk, with a capacity of 70,000 litres of milk per day, is planned Three milk collection centres have been set up in the Baghdad area by the Dairy Administration, which operates the UNICEF-assisted Government dairy factory The milk is cooled in the collection centre, and transported to the plant in insulated tank trucks The collection centre farthest from the plant is at a distance of about 30 km. It has been proposed to establish another collecting centre in an irrigation project about 70 km from the factory, where settlement took place several years ago on land which had just been provided with irrigation and drainage canals Settlers in the project had started to grow fodder crops for dairy cows kept to meet the needs of their own families

Plans are being carried out for the removal of all cattle and buffaloes outside the city limits of Baghdad and their housing in modern and sanitary settlements This programme will comprise about 1,200 families who own about 30,000 buffaloes and cows It is hoped to complete the transfer within 18 to 24 months

Barns have been erected for a model dairy farm next to the dairy factory, and land obtained for fodder and pasture production The farm would have 2,000 head of cattle, the area under fodder crops would be 1,250 hectares Costs of production of pasture and fodder, including overhead costs, are

	Iraqi Dinars per ton of green feed
Grazing	0 858
Soilage	2 532
Hay	2 761
Silage	3 220

Van der Veen(143) states that production per hectare from permanent

irrigated pastures is considerably lower than from lucerne, and that grazing of mixtures of annual winter cereals and legumes, such as oats/berseem or barley/berseem is feasible and was practised at the Abu Ghraib Experiment Station. Grazing is, however, not recommended for first-generation crosses with exotic cows because of the health hazard (tick-borne diseases such as piroplasmosis). Second-generation animals from local introduced crosses appear to have more immunity.

TABLE 25

Iraq. Carrying capacity of irrigated fodder crops in central Iraq (Based on average green yields, and on requirement of cow of 900 lb. body weight, producing 5 litres of milk daily for 300 days, as given in Morrison's 'Feeds and Feeding')

Crop	Average green yield tons per hectare	Number of cuts (or grazings)	Number of cows maintained per hectare	Length of period of availability (months)
Lucerne	100	8–11	8	10
Permanent pasture	52	7–9	5	10
Berseem	60	4–5	10	4–5
Sorghum	32–40	2–4	11·2	4
Sudan grass	28	4–5	5·2	5
Cowpeas (*Vigna sinensis*)	12	1–2	2	3
Phaseolus radiatus	16	1–2	*	*

* No data on feeding value given in *Feeds and Feeding*.

IRAN

The irrigated perimeters within the irrigated arid zones of the central Iranian plateau lie mainly at the foot of the Zagros Mountains (Ispahan, Kerman) and of the Elburz Mountains (Teheran). According to the FAO/UNESCO/WMO agroclimatology project,[56] the arid continental climate has generally cold winters with minimum temperatures below 3° C. and 7° C. respectively for 60 to 80 days, and 100 to 120 days. The spring rise in temperatures is rapid, around 5° C. per month. The precipitation of 100 to 250 mm. falls for a prolonged period but the regular rainy season is quite short; December to late April in stations where precipitation is around 200 mm. The relative inter-annual variability is high (55 per cent) because of the low rainfall. The relative air humidity is never very high and is often below 50 per cent in the middle of the

day. The annual evapotranspiration (ETP) values vary little (1,300 to 1,500 mm.) and remain below 40 mm. per month for 3 months; they rise very rapidly in spring Precipitation covers ETP needs for only 1 to 3 months The summer season lasts for about 6 months but may be 7 months at elevations below 1,500 m. The maximum temperatures exceed 35° C for 2 to 3 months, the sums of mean temperature lie between 1,500° C and 1,700° C ETP water requirements during the summer season exceed 1,100 mm. and in July the ETP values rise to about 230 to 250 mm.

Cultivation is feasible only in irrigated areas The semi-late wheat varieties such as Fahravan are recommended, while Coker Wilt 100 cotton, gourds, sorghum and sugar beet are the main summer crops at present being developed The summer season has several points in common with the summer seasons in the western part of the Fertile Crescent (slightly shorter) and in the San Joaquin Valley, California.

Obviously lucerne should be the best adapted cultivated fodder crop Lucerne hay (usually stalks with the leaves missing) is fantastically costly in the Teheran markets, far too high in price for economic milk production, due to an inflated idea among the cowkeepers as to its feeding value If it is to be the basis of a dairy industry, it should be competitive in economic return per hectare with the major food and cash crops on the irrigated land. For this purpose it would have to be fed to highly productive animals and the proportion of milking to dry animals and growing stock would have to be high. It may be desirable to subsidize the cultivation of lucerne and other fodder crops for a number of years until their value has been appreciated and the required livestock population has been developed. Apart from high quality fodder crops fed green or conserved as hay or silage, there will be a certain amount of crop residues available from the arable crops to provide part of the maintenance ration Only 10 per cent of the natural grazing lands of Iran are susceptible of improvement by reseeding, and even they could not be expected to provide grazing pastures up to the requirement of productive dairy animals

One must conclude that, in the present circumstances, the dairy industry in and around Teheran must rely heavily on concentrate feeds, perhaps for part of the maintenance and all the production ration, particularly since most of the stock are in the town dairies Iran exports most of its cotton-seed but by agreement with the companies concerned with the extraction of oil, the export of cotton seed cake will be authorized only after local consumption has been secured. Silage made from

beet pulp is now being used extensively in livestock feeding, and there are some factories which dry beet pulp for animal feeds.

Later we may hope for a greater integration of cultivated fodder crops into the farming patterns, with all that this means in reduced costs of production and higher fertility for the individual holdings. In assessing the position within the Teheran milk procurement area, one would need to know what other types of animal husbandry and production are competing for the actual and potential fodder resources. It is stated that there is in the Teheran area no significant competition from any other type of livestock production, and that most of the feeds and fodders are therefore available for the dairy animals.

As the continuous increase in the price of fodder and feeds is creating a serious economic position for the dairy farmers, credit should be given for the purchase of additional land for pastures and for fodder production.([55]) The Ministry of Agriculture should do everything possible to promote the cultivation of fodder crops as a basis for dairy farming, by increased experimentation on dryland and under irrigated conditions, by demonstrations on farmers' fields and by the granting of special advantages to farmers who grow fodder crops. According to local custom, milk producers are given advance payments from the buyers when they sign their contracts, and this practice has been retained in the transactions between the producers and the Government Dairy Factories, in order to help the producers to improve feeding and management and the buildings on their farms. Action has also been taken by Government to provide land for milk producers, to encourage them to move their enterprises out of the city of Teheran, and to change from the present system of dry-lot feeding to a typical dairy farming system. A new division for the study of fodder production under irrigated, dry farming and range conditions has been set up in the Department of Animal Production, Ministry of Agriculture.

The cropping pattern in the Central Ostan of Iran, in which Teheran is situated, may be seen in Table 27. It will be seen that only 9,600 hectares out of a total area of irrigated and dry land in the province of 392,000 hectares are under lucerne, sainfoin and other fodder crops. For Iran as a whole, the figures are 148,000 hectares of lucerne, sainfoin and other cultivated fodder crops out of a total area of about 6 million hectares under cultivation. The dairy extension agronomist certainly has great scope for his activities. And within economic transportable radius from Greater Teheran there are three areas of irrigated development, which in order of potential are:

1. Karaj-Kazvin—situated to the west of the city with better-quality irrigation water.
2. Varamin-Garmsar—situated to the east, with poor to medium quality irrigation water (in terms of relative salinity)
3. Shahr-Rey—South Teheran—mainly ground water of mixed quality.

There are 144 dairy farms which are under strict inspection for milk sanitation, and which supply two-thirds of the total milk produced for two important milk pasteurization factories The number of farms and cattle populations found in these areas are shown in Table 26 The Government considers that the greatest potential for development of dairy farming is to be found in Karaj and Shahriar.

TABLE 26

Iran Dairy production around Teheran

District	Number of Dairy Farms	Cows in milk	Heifers	Milk production (litres per day)
Karaj	10	1,477	388	3,830
Ghala Hassan Khan	5	160	32	720
Shahriar	16	1,877	419	6,944
Shahr Rey, Varamin	17	2,774	666	8,508
Teheran	64	16,226	1,992	49,329

If the ancient distinction between crop husbandman and animal husbandman characteristic of the Near East can be broken down, and the cultivators in these irrigated perimeters can be given the necessary incentive to take up dairy farming as a major industry, there is a great potential for development in this direction

TABLE 27

Iran Crop areas in central Ostan, 1960 (excluding fruit trees and vines) in hectares

	Unirrigated	*Irrigated*
Wheat	118 809	144,019
Barley	28,390	36,917
Total wheat and barley	147,199	180,936

TABLE 27—*continued*

Iran. Crop areas in Central Ostan, 1960 (excluding fruit trees and vines) in hectares

	Unirrigated		*Irrigated*
Rice	—		—
Millet	—		55
Sorghum	—		—
Other Cereals	—		—
Total cereals	147,199		180,991
Legumes	1,843		3,157
Lucerne and sainfoin	—		7,378
Other fodder crops	228		2,282
Potatoes	—		2,679
Vegetables	—		3,489
Melons, cantaloupes, etc.	2,788		13,301
Sugar beet	—		682
Beet for seed	—		—
Sugar cane	—		—
Spices	—		—
Oil seeds	—		1,684
Cotton	—		24,748
Fibre crops	—		—
Tobacco	—		—
Total: crops other than cereals	4,779		59,397
Total: all crops	157,978		240,388
Total crops		392,366	
Wheat and barley	96·9		75·3
Total cereals	96·9		75·3
Other crops	3·1		24·7

TABLE 28

Iran. Livestock population (Agricultural Statistics, 1960–1)

Livestock	Total for Country	Central Ostan
Cows and calves	4,980,800	250,500
Buffaloes	234,900	150
Sheep	15,959,300	1,195,700
Goats	12,080,500	795,700
Donkeys	1,753,300	147,700
Mules	85,400	4,500
Horses	309,500	5,500
Camels	176,900	9,200
Hogs	7,200	—
Poultry	13,433,600	721,400
Other fowls	866,700	8,100
Number of livestock owners	2,064,840	145,060

MONSOON ASIA

PAKISTAN

KARACHI

According to a report by M Lamer, FAO, the Karachi milk factory was nearing completion at the time of his visit, October 1963, but could not be expected to start operations before summer, 1964 'The factory will face the crucial problem of having an insufficient milk supply immediately after the start of operations' In the first phase, the daily production was planned to be 25,000 litres of toned milk (2 per cent fat), the maximum was to be about 75,000 litres of daily throughput spread over three shifts 'The Report of the Team Representing Countries Exporting Dried Skim Milk on Possibilities for International Co-operative Action in Pakistan' estimated in 1957 that the daily potential milk supply of Karachi was 200,000 litres of city milk, and 75,000 litres of milk from rural areas Actually the city milk supply is about 20,000 litres, and is too high in price to be used for low income groups In the rural areas within a radius of 96 kilometres from Karachi, there is less than 5,000 litres of raw milk (6 per cent fat) available in the Charo and Thatta areas, enough to cover only half of the initial planned production of toned milk.

There exists a potential for developing milk production in the Thatta region, but the Agricultural Development Corporation has made no provisions in this respect The irrigation recently introduced in this area has been concentrated on large mechanized farms with rice monoculture without any attempt to incorporate livestock and fodder cultivation into the farming pattern As this area is now waterlogged, the livestock owners have been obliged to migrate to the hills, insufficiency of fodder has compelled the slaughter of cattle, and the milk supply has thereby been reduced rather than increased

It will therefore be necessary to investigate the possibilities of obtaining milk in areas far from Karachi and transporting it by road or rail There is a possible area 400 to 560 kilometres from Karachi (10 hours by rail) at Dadu Larkana, the supply from the Punjab (W) has also to be considered in spite of the long-distance transport that is involved Studies of milk potential and the possibility of greatly increasing fodder supplies should have been undertaken earlier and not when the factory is starting operations

LAHORE

Milk is stated by M. Lamer, FAO, to be readily available for the Lahore milk scheme from a radius of 64 kilometres from the city. The factory should come into operation in 1964; as a demonstration of a successful enterprise, it should have been established before Karachi. There is stated to be enough to supply 25,000 litres per day of toned milk from the Lahore factory and to allow for further expansion.

RAWALPINDI

The FAO/UNICEF team that visited the area in March 1963, considered the future milk requirements of the city of Rawalpindi and the new federal capital under construction at Islamabad. Rawalpindi is itself situated in a milk-deficient area and the supply position will be made more difficult by the appropriation by the Capital Development Authority of some 200 square miles of agricultural land adjacent to the city. Much of this land will subsequently be diverted to non-agricultural use, thus further depleting direct supplies of milk to Rawalpindi, and affecting the present source of feedstuffs for the city herds.

The team surveyed three possible areas for rural dairy development, referred to as the Murree Highway and Kahuta Road area, the Haripur area and the Jhelum River area. Only the last of these three was found to have any great potentialities for milk production. It is a rich and well-developed agricultural region, with much of the land under irrigation from the upper and lower Jhelum canals and a climate suitable for fodder cultivation in all seasons. There is a relatively high concentration of buffaloes, with individual herds of five to ten animals each. Land holdings are relatively large with many in the 3 to 5 hectare category, and 10 to 20 per cent of the holdings are under berseem, wheat and oats for cutting green. Considerable quantities of whole cotton-seed (rather undesirable) and oilcake are fed. The area specializes in ghee production with little if any sale of whole milk. The establishment of a chilling-pasteurizing plant at Mandi Bahauddin (200 kilometres by rail from Rawalpindi) would represent a considerable incentive to the producers.

It is apparent that here, as in Punjab (India), the production of green fodder does not represent a great obstacle to dairy development. It is possible to define targets for a wider range of crops on the seasonal conveyor belt for feeding in the green or conserved state, in relation to the feeding requirements of the total buffalo population (in milk, dry and

followers) needed to produce the initial planned amount of 15,000 litres per day An initial survey of the production phases would also consider the possibility of reaching the second phase milk target of 100,000 litres per day from the Jhelum and other areas Such a development requires to be supported by arrangements to ensure a reliable source of seeds and fertilizers, if possible at concession rates for the initial years Extension officers should also conduct demonstrations of improved feeding methods, which will probably lead to a production per animal two to three times the present level

DACCA

East Pakistan is one of the most difficult areas in which to develop an adequate fodder basis for an economic dairy industry There is so little room for manœuvre The small size of the holdings, the predominant need to produce food for direct human consumption, the intense competition between man and animal, and the nondescript nature and abysmally low productivity of the bovine population, all these and other factors militate against the early development of a new and stable form of land use based upon alternate husbandry or mixed farming It is difficult to see how dairy animals, buffaloes or cows, can be fed on anything other than paddy straw and other low-quality crop residues, and concentrates From the experience at Haringhata Farm in West Bengal, India, we know that a sequence of fodder crops may be grown to provide green feed throughout most of the year, but it is unlikely that cultivators will agree to spare any of their land for their cultivation

There is need for a production survey on the lines of that carried out for the Hyderabad/Vijayawada Integrated Project in Andhra Pradesh, India (see Chapter XIII), to show whether the 30,000 pounds of milk per day needed to operate the Savar plant are available on a reasonably uniform basis throughout the year, and within what radius of Dacca This would provide a basis for the pilot scheme of milk collection that was proposed by the FAO/UNICEF team that visited the area in February, 1963, and now the objective of second phase planning. The survey would also indicate the directions in which the dairy extension efforts in animal husbandry and fodder agronomy should be concentrated, whether subsidies for seeds, fertilizers or per acre of crop are desirable, and what other credit facilities should be provided These actions in the production phases should, of course, be supported by the formation of rural dairy co-operatives, artificial insemination centres and other breeding facilities, veterinary hospitals and dispensaries There is, how-

ever, the further difficulty that Savar farm may be isolated for 3 to 4 months from Dacca, and milk has to be transported by truck/boat/truck provided the weather is not too rough.

But it may be asked what happens to the sewage of a city the size of Dacca (more than 500,000), or what is planned in the way of disposal in the future. Is there any waste land or land of low productivity within 20 or 30 kilometres of the city to which the sewage could be economically pumped, and at which a cattle settlement could be established with ample year-round supplies of green feed? If so, the authorities responsible for public health and dairy development should get together to plan for sewage utilization, not disposal. Such fabulous yields of grass may be obtained per acre that it might even be economically sound to retire some land from continuous low-yielding paddy, and place it under sewage grass.

INDIA

There have been many references in the foregoing chapters to the problems of producing milk in India, and to the measures which may be taken to overcome them. In addition, the whole situation in that country has been described in the partner book by Whyte and Mathur[168] entitled *The Planning of Milk Production in India*, and in the earlier book entitled *The Grassland and Fodder Resources of India.*[160] It is, therefore, necessary to give here only a relatively brief summary of a complex and difficult situation.

In India perhaps more than in any other developing country, we have a reasonably clear idea of the targets of milk production that must be achieved if every person is to receive an amount of milk and milk products necessary for correct nutrition. These are 133 million litres per day to meet the objective of 0·28 kg. or 10 ounces per head per day suggested in 1944 by the Nutrition Advisory Committee of the Indian Council of Medical Research, or 80 million litres per day if calculated at what is currently considered to be a more realistic target, namely 0·17 kg. or 6 ounces per head per day.

These targets have recently been expressed in agricultural and animal husbandry figures, as follows:

(*a*) The total number of productive bovines needed to produce these amounts of milk, assuming that 25 per cent of that population is in milk at any one time, and recognizing that the number of animals (cows or buffaloes) required is related to yields which vary

from 500 to 2,500 litres per lactation, but with a national average near the lower figure

(b) The total amounts of locally available concentrate feeds and green and dry fodders needed to feed this bovine population according to accepted standards in India

(c) The areas of cultivated land needed to produce the required amounts of green and dry fodders, having regard to the average yields of the crops concerned under the ecological conditions of the milk plant in question

These calculations on a national basis, and also broken down into the requirements for individual milk plants varying in daily input from 2,000 to 250,000 litres per day, are given in *The Planning of Milk Production in India*

Against these targets we must place the available resources and these have also been analysed on the basis of such information as is available

The concentrates and oilcakes amount to about 10 million tons The demand to feed the bovine population of India correctly is about eight times that amount The demand for working animals and poultry plus the bovines needed to supply to capacity (3 million litres) of the milk plants now (1966) in operation or under construction (Table 5) is six times the available supply

Data regarding the area of fodder crops and production are not reliable as these are not scheduled crops for statistical purposes in Panchayat records The total production may be said to be around 150 million tons, assuming a yield per acre of 10 metric tons green, and the demand is about 600 million tons

Taking the average yield of straws and other residues from cereal crops at two thirds of a metric ton per acre, the amount available would be about 150 million tons to meet a requirement of 870 million tons Some increase in the amounts of crop residues may be expected from the application of fertilizers for increased production of grain, rather than from any marked increase in the cereal acreage as such

With the present information and techniques that are available, it is difficult to assess the actual or potential contribution of natural grazing lands to the overall feed resources for milk production Village pastures and grazing grounds within daily walking distance from the villages are grossly overgrazed, sometimes carrying ten to twenty times the number of bovines that should be sustained by that particular type of grass community On the other hand there are vast areas inaccessible to cattle which should be used for the cutting of hay Although the species in the

natural grass covers do acquire some degree of quality during the latter part of the monsoon months, they are for most of the year low in protein and high in fibre, and as such of no value to productive milch animals.

But even if it were possible to provide the feeds and fodders that are required, as the basis of an economic dairy industry, we are still left with the greatest problem of the whole developing world, the so-called 'cattle wealth' of India. Anyone who has eyes to see what this anachronistic situation, based upon a combination of sentiment, prejudice and religion which motivates those who support the responsible politicians, is doing in the destruction of the land of India may be pardoned for feelings of deep anger and frustration. Nothing can be done in the conservation of forests or grasslands, nor in the better management and conservation of soil on the cultivated land nor in improving human nutrition, until the policy-makers take courage and face the economic realities of cattle management for the sake, in the first place, of the land and the people. A complete reversal of national policy is called for, preceded by an intensive programme of education and propaganda, perhaps to be initiated by a revered religious leader.

As far as the milk production targets of the country are concerned, there is no indication that the present cattle population is in any way adequate to meet the demand. Key Village Schemes or Intensive Cattle Development Projects([170]) can make a limited contribution, but one is always conscious of the hopelessness of the general situation throughout the country, as long as the breeding of cattle is based upon the prohibition of culling by slaughter.

The cattle situation may be presented as given in Table 29. The estimated economic bovine population under (b) is an optimistic figure, and probably exaggerated.

Therefore, to meet the lower nutritional target, it would be necessary to have double the present estimated productive bovine population, giving 1,000 and not 500 litres per lactation. It would also be necessary to eliminate all the animals of lower productivity in order that the limited feed and fodder resources could be used for production.

The real test of the economic efficiency of the dairy industry in India comes when one calculates the contribution of feeds and fodders within the total cost of production of 1 litre of milk. Over 80 per cent of milk produced in India comes from buffaloes, and in calculating these costs of feeds and fodders, it is customary to consider only the amounts fed during the actual period of lactation. If the farmer buys the buffalo

before it has calved, and feeds it properly during the final stages of pregnancy and throughout the lactation, we should calculate on the basis of 400 days The costs of feeds and fodders per litre would then be Rs. 1·55 for whole milk and Rs 1 07 for fat-corrected milk and 4 per cent.

TABLE 29

India Calculation of present and required population of milch animals

(a) *Cattle* (1961 *Census*)	Thousands
Males over 3 years	72,500
Females of breedable age in milk and dry	54,300
Young stock	49,000
Buffaloes (1961 *Census*)	
Males over 3 years	7,700
Females of breedable age in milk and dry	25,000
Young stock	18,500
(b) *Cattle*	
Percentage of females of breedable age considered to be worth maintaining and feeding for economic milk production—25 per cent	13,600
Buffaloes	
Percentage of females of breedable age considered to be worth maintaining and feeding for economic milk production—80 per cent	20,000
Total milch stock estimated—basis of 1961 census	33,600
Percentage in milk—50 per cent	16,800
Production of milk per day from this population at 500 litres per lactation, ignoring the Government of India estimate of 250 litres for cows	21,000
(c) *Bovines in milk*	
With lactations averaging 1,000 litres required to provide 80 million litres per day (6 ounces per head of human population per day)	32,000
Females of breedable age in milk and dry required to provide 80 million litres per day	64,000

But a milkman may purchase the buffalo just after calving and sell it upon completion of a lactation of, say, 300 days In such circumstances, the feed and fodder costs are Rs 1 25 and Rs 0 85 per litre for whole and fat-corrected milk respectively, at market rates for concentrates and green and dry fodders current in Bangalore in April 1966 * At the National Dairy Research Institute, Karnal, Punjab, these costs, based

* Before the 1966 devaluation of the rupee.

on farm-grown fodders, were Rs. 0·52 per litre for whole buffalo milk and Rs. 0·35 per litre fat-corrected milk at 4 per cent.

If, however, we calculate the feed and fodder component of the total cost of producing a litre of milk on the assumption that the farmer rears his animal from birth and feeds it according to accepted standards until the end of its final lactation, we obtain figures of Rs. 5·48 or Rs. 3·78 per litre for buffalo milk, whole and fat-corrected respectively.

The retail price of whole buffalo milk is Rs. 1 or more per litre, and of toned milk, around Rs. 0·6 to 0·7 per litre.

It is interesting to calculate whether it would be possible in India to achieve the national target of 80 million litres per day (32,000 million litres per year) by combining high-fat buffalo milk with imported skim milk and water. This target could be reached by combining a daily production of 32 million litres of buffalo milk with an annual supply of 1,600,000 tons of imported skim, plus water. To produce 32 million litres per day, India needs 51,200,000 buffaloes of breedable age in milk and dry, giving the national average of 500 litres per lactation. According to the 1961 Census, the population of buffaloes in these categories in India is 25 million.

The buffalo must nevertheless remain the primary milk-producing animal over most of India, until such time as the national breeding policies for all types of livestock in general and for milk-producing crossbred cows in particular have been worked out and their implications accepted in terms of genetical, economic, social and political change.

CEYLON

As a result of the hot and humid climate, tropical crops are the main source of agricultural income. The cultivated tropical grasses grow well, as compared with legumes, but livestock farming is not sufficiently remunerative to permit these fodder crops to compete with tropical cash crops. Large quantities of rice straw are, of course, available, but this is fed mostly to the draught animals because of its limited nutritive value for milch animals. A more important source of feed might be the substantial quantities of rice bran. This resource is largely wasted, because the small country mills are not usually in a position to separate the bran from the husk. The large production of coconuts on the island would suggest that coconut cake would be a more readily available concentrate.

Apart from the difficulties of providing cattle feed in adequate quantity and quality, the climatic conditions are the most serious obstacle to intensive animal husbandry High humidity has an adverse effect on the growth and milk production of cattle Imported animals kept under local conditions of husbandry deteriorate rapidly To maintain their health and resistance cows and also buffaloes are washed down several times a day There are at present about 1 5 million cattle and about 800,000 buffaloes in Ceylon, and it is estimated that 810,000 of the cattle are milch cows and heifers Contrary to the situation in India, buffaloes are relatively unimportant for milk production and only about 80,000 are listed as milk animals The 300,000 tons of buffalo milk produced annually are generally used for curds and only limited quantities find their way into the liquid milk market.

Most of the cattle on the island are of the Sinhala race, an indigenous Zebu type which breeds more or less pure, but yields little milk The bullocks of this breed provide the main source of draught in Ceylon Even under optimal conditions of feeding and management, the cows do not produce much more than 400 litres per lactation

There are about 2,500 animals of European type, mostly Friesian, Ayrshire and Jersey Importation of these animals began during the last war when about 1,600 were brought in from Australia Since then, there has been occasional importation of bulls The condition of these western breeds of cattle is very unsatisfactory and the mortality rate is high The cattle which are kept on Government farms, more than 2,500 cows of the Indian breeds, Sindhi and Tharparkar, are in a much better condition The bulk of the cow milk in Ceylon, however, comes from about 18,000 crossbred cows, which are mostly crosses between Sinhala and European type cattle at various stages of crossbreeding The most important groups are the so-called Hatta cows, kept mainly by the workers on the large tea estates in the south of the island

Milk production is primarily in the hands of small scale producers, the most important group being smallholders with one or two cows each, living in villages All milk not required by the family itself is sold by the producer to his neighbours or to the local tea kiosk. There is also a substantial number of small scale producers in the urban and suburban areas of large cities who sell highly adulterated milk direct to city consumers Large-scale production of milk is carried out only on some of the coconut estates and the Government farms

Milk production actually declined between 1948–52 and 1960–2, due primarily to a decline in the production of buffalo milk. Because of the

rapid increase in human population, the production *per caput* is now lower than during 1948–52, even though there has been a very considerable increase in the number of cows and buffaloes. This would indicate considerable decline in milk yield per bovine. The scarcity and inaccuracy of statistics make it difficult, however, to draw concrete conclusions. Yet in recent years production *per caput* of human population remained virtually constant at the very low level of about 12 litres per annum.

BURMA

Although Burma is pre-eminently an agricultural country, there has been little attempt to develop a livestock industry, apart from the breeding of draught animals. This type of livestock production is, of course, very important to the economy of a country in which the cultivation for the paddy crop is done by bullocks and buffaloes. Little has been done, however, to establish a dairy livestock industry or to make any improvement in what little dairy industry is already in existence.([40]) It is considered that the conditions in the Union would be excellent for such an industry. There are large tracts of grazing land, almost unused. There is abundant rainfall; the country can produce all the concentrates which would be required, and there is a large drain on the foreign exchange resources because of the importation of large quantities of milk and milk products.

Certain factors operate against the establishment of a thriving livestock industry, or even the improvement of the present industry, namely:

(*a*) Lack of any trained or subordinate staff in the Government Department concerned with the welfare of livestock.
(*b*) Absence of co-ordinated effort by Government regarding improvement of livestock.
(*c*) Cattle Slaughter Prohibition Act.
(*d*) Impact of Buddhism.
(*e*) Lack of security.
(*f*) Scarcity of foreign exchange.
(*g*) An almost total lack of interest in the various States in matters relating to livestock production.

Due to the large number of cattle which was slaughtered during the Second World War, and in order to build up to the pre-war level, the Union Government passed an Act in 1947 which allowed the slaughter of only the following classes of cattle:

(*a*) Male cattle above fourteen years of age which are unfit for work.

(b) Animals of any age which could not be used for draught because of injury or deformity
(c) Female animals which were unfit for work or breeding due to injury or deformity

Cattle suffering from diseases such as tuberculosis, or animals which are totally uneconomic, cannot be destroyed

According to a subsequent report(59) the Government clearly recognizes the need for the increased production of animal products for human consumption at a price which the people can afford The problem concerning this country is the means by which such an increase might be achieved

There is a shortage of trained personnel possessing experience in modern animal husbandry There is little capital available to the villager, no animal husbandry extension service, and no organized marketing facilities to protect the farmer from the middleman Apart from poultry in the Rangoon area, there is little economic incentive to increase and intensify production The rigorous monsoonal climate over much of the country imposes severe restrictions on plant growth and storage of fodder The primitive methods used for the preparation of oilcakes and fishmeals lead to the production of protein concentrates of highly variable and inferior quality Owing to the intensive use of rice bran in particular, there is an urgent need for research to show how it may be protected from becoming rancid and losing its feeding value Pelleting of the rice bran with the protein concentrates, vitamin and mineral supplements, and the use of anti oxidant to protect the oil in the rice bran may be used in the preparation of concentrates

Although heavy grazing is, as in India, undoubtedly the cause of the general deterioration of village common grazing lands to a completely unproductive state, it is considered that their rehabilitation through replanting and controlled grazing is both feasible and necessary Certain grass and legume species were introduced from Australia in collaboration with the Division of Tropical Pastures of CSIRO

The most successful species in the Rangoon area, under ungrazed conditions, were seen to be *Paspalum plicatulum*, *Brachiaria decumbens* (on more fertile soils), *B brizantha*, *Cenchrus ciliaris* and *Hyparrhenia hirta*, while, among the legumes, *Phaseolus atropurpureus* was outstanding and *Stylosanthes gracilis* showed promise (145)

The natural grasslands of Burma resemble certain of the types of grass cover in India described by Whyte, Dabadghao and Shankarnarayan.(163) Recommendations that funds should be provided by the Government

for a study of the ecology and management of natural grasslands should be considered in relation to remarks made elsewhere in this publication. Although the natural monsoon grasslands of Burma may be expected to provide a certain amount of grazing for bovines of low productivity, they cannot be expected to make any major contribution to a dairy industry. As in India, therefore, any development leading to increased milk production must be based on the feeding of superior bovines with cut fodder from cultivated land.

Apart from these considerations regarding the difficulty of producing milk economically from poor quality animals in a monsoonal climate, it should be noted that the Burmese do not normally drink fresh milk and that any attempts to change their dietary habits are likely to be slow in effect. Any such action would have to be supported by incentives such as low prices to the consumer, which necessarily would mean low prices to the producers. Dairy farmers would therefore be unable to adopt a feeding system demanding purchase of concentrates. Hence the great importance of pasture and fodder development in the establishment of an economic dairy industry in the country.

More recent information confirms that the standard of dairy husbandry in Burma is very low and that it would be difficult to find a herd where the average production of milk per day exceeded 4 litres per cow. The herds on Government farms are no better than the average, and would be even inferior to those of the better Indian dairy farms. The cows are a mixture of local breeds crossed indiscriminately with Indian breeds. The Red Sindhi breed is considered to be the best and is the most popular, but there has been no attempt to use bulls from the best cows nor to select bulls which have sired proven daughters.

The standard of management in dairy units is very low. Calves are still used to produce 'let-down' of milk. On Government farms the cost of concentrates must exceed the value of the milk produced. Maturity of the animals is slow, many cows not calving until four years of age. As far as animal diseases are concerned, mastitis is common. Some reports indicate that tuberculosis is not common, while other tests have shown many positive results. There are periodic outbreaks of foot and mouth; Johne's Disease is common, and is probably the cause of serious wastage of livestock. Haemorrhagic septicaemia is the most serious disease of cattle and buffaloes and most cows are vaccinated against this.

There has been virtually no effort to grow improved pastures or fodder crops. Green grass is obtained from any available source, and most herds depend upon the basic rations of rice bran, augmented by

broken rice, maize grain and oilcakes fed according to their individual price and availability The hay which is used has a very low protein content Private dairy farmers are now being forced out of business because they cannot afford to buy feeding stuffs The sale of concentrates is under Government control and restriction

Improved pastures are being recommended at the present stage because they seem to be the simplest way to start a programme based upon improved animal feeding The intensive cultivation of fodder crops cannot be recommended for Burmese conditions since the cows which are capable of the high yields necessary in this system are just not available, nor is it possible to get rid of the numbers of disease ridden, unproductive stock of the country

There is still ample land available in Burma and it is believed that crop production could be markedly improved, if combined in an effective rotation with temporary grass pastures While this system demands the maintenance of large herds of low producing cows, it is nevertheless more efficient to let the cows at that level of production harvest their own feed and distribute their own droppings One of the important problems at present in Burma is to induce the cattle owners to take the manure which accumulates around the sheds back into the fields If productive pastures can be established, the cows may then be upgraded, and zero grazing and the intensive cultivation of high-yielding fodder crops may be achieved

PHILIPPINES

There are at present four major sources of supply of milk in the Philippines locally produced whole fresh milk, 'filled milk' (combination of imported skim milk powder with a blend of refined coconut and maize oils, reinforced with vitamins A and D), manufactured 'recombined' milk, and imported milk (see Table 30) It is estimated that more than half the total supply is whole fresh milk not normally entering commercial channels and representing the milk supply at the farm or barrio level, where two thirds of the population live Milk classified in this category is, according to W J A Payne,[120] for the most part obtained from carabao, crossbred and pure Murrah buffaloes, indigenous cattle and goats

The Government of the Philippines through the Bureau of Animal Industry, and supported by the FAO technical officers of the Dairy Training and Research Institute (United Nations Special Fund Assisted

Project), are taking vigorous action to establish a modern and efficient dairy industry in the country. A Dairy Act (R.A. 4041) provides funds for loans to potential dairy farmers, for the establishment of pilot plants by the Bureau of Animal Industry, and for the activities of the Dairy Training and Research Institute.

TABLE 30

Philippines. Estimated quantity of milk produced or imported (million kg.)

Source: First City National Bank (1963).
Data in parenthesis represent percentages of the total.

Source	1960	1961	1962	1963
Whole fresh milk:				
Commercial	10·7 (2·6)	10·8 (2·7)	11·2 (2·6)	11·5
Non-commercial	232·3 (57·5)	228·9 (56·4)	241·8 (56·4)	Not estimated
Filled milk	101·0 (25·0)	115·0 (28·3)	128·0 (29·8)	128·0
Recombined milk	—	—	—	55·0
Imported milk	60·0 (14·9)	51·3 (12·6)	48·0 (11·2)	Not estimated
Total	404·0	406·0	429·0	

There is already a considerable market for milk and milk products in the Philippines. The existing market amounts to 300,000 metric tons annually of liquid whole milk equivalent. FAO economists have estimated that the effective demand is likely to increase to 550,000 metric tons by 1975. This market exists without any expansion due to increase in purchasing power or any other cause. The present import bill for dairy products is $30 million per annum. Industrialization is proceeding. The number of persons engaged in agriculture decreased from 70 to 59 per cent of the total population (nearly 30 million) between 1930–44 and 1945–61. Although the income per head is very low, at least 10 per cent of the total population can afford to pay the economic price for fresh milk. When fresh milk becomes available, it is fully expected that the local demand will increase rapidly, although there is undoubtedly a local preference for carabao milk.

The seven major climatic zones of the Philippines shown in Fig. 8 are based on the most important factor, rainfall. Of a total area of 30 million hectares, not more than 8 million hectares are used for the production of the main crops, rice, maize, coconuts and sugar. In the more inaccessible parts of the country, there are some 13 million hectares of forest land, most of which has already been cut over. This, together

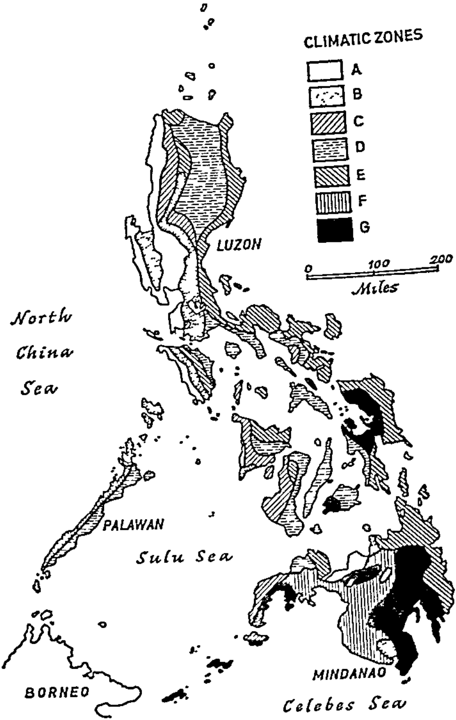


FIG. 8. Philippines—seven major climatic zones at low altitude.

with part of the nearly 9 million hectares of so-called waste land, is regarded by some as suitable for grazing. In addition, a large proportion of the million hectares under coconuts could also be developed as grazing land.

Much of the deforested land of potential value for grassland development is of easy contour, in large homogeneous blocks of open grasslands each about 2,000 hectares in size, and appearing to be well suited for livestock production, although the present low-quality indigenous grasses would probably have to be replaced by sown or planted superior types within fenced and fertilized pastures. Bukidnon Province, for example, located in the centre of northern Mindanao, consists of a wide plateau at 700 to 1,000 m. altitude dissected here and there by deep valleys. This region enjoys the most favourable rainfall for pasture and animal production. In addition to Bukidnon, other areas favourable to cattle husbandry are Davao and Cotabato in southern Mindanao, Lanao in northern Mindanao, areas in the Visayas, the Bicol region in southern Luzon and parts of northern Luzon. Thus there is not yet any sign of competition for land resources between a developing animal industry and the production of crops for direct human consumption.

Statistics suggest that there are about 3·5 million swamp buffalo or carabao in the country. Most are kept for draught, although perhaps 2 per cent are kept for the production of liquid milk and cheese for the market, and a larger but unknown number for milk production for the farmer and the village. It is said that carabao produce 1 litre per day for 200 days in addition to feeding their calves. Crossing with imported Murrah buffaloes has not succeeded.

Up to the early years of this century, the cattle consisted almost entirely of animals indigenous to the country, of the *Bos taurus* type,

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Old Classification	*New Classification*
1. Dry winter and spring. Wet summer and autumn.	A. Long low sun dry season: 5 or 6 months with less than 6 cm. rain per month.
	B. Intermediate low sun dry season: 4 months with less than 6 cm. rain per month.
2. Short dry season of 1–3 months.	C. Short low sun dry season: 1–3 months with less than 6 cm. rain per month.
	D. Short high sun dry season: 1–3 months with less than 6 cm. rain per month.
3. No dry season. Pronounced winter rainfall.	E. All months with 6 cm. or more rain: wettest low sun month with at least three times the rainfall of driest high sun month.
	F. All months with 6 cm. or more rain: wettest high sun month with at least three times the rainfall of driest low sun month.
4. No dry season and no pronounced maximum rainy season.	G. All months with 6 cm. or more rain· wettest month has less than three times the rainfall of the driest month.

Note: High sun period is April through September. Low sun period, October through March.

reputedly introduced many hundreds of years ago from the mainland of China Present day indigenous cattle are small, 200 to 300 kg live-weight, similar to the Jersey in appearance, colour and conformation, males being useful for draught and beef, females giving sufficient milk to feed the calf and no more Indian and temperate zone breeds were imported from the beginning of the century, and from 1945 to early 1962, the Government and private farmers have imported some 8,300 head of cattle representing twenty European and other breeds A rough idea of the breed composition upon which a dairy industry would have to be developed has been given by Gerring[71] as follows

Native indigenous stock	500,000
Introduced Zebu breeds and their crosses	500,000
Introduced dairy breeds of Western and Eastern origin	3,000
Grade 'dairy' cattle	7,000

Two large private operators have maintained some 750 Holstein-Friesian and 350 Jersey cattle as pure breeds, to supply milk to the city of Manila Cattle of European origin require almost continuous housing to protect them from climatic stress, combined with a high level of concentrate feeding to obtain reasonable levels of production Despite these measures, mortality among both young and adult stock is often high, and the proportion of dry animals in the herd is also high, due to long intervals between calvings These difficulties are, of course, accentuated in less favourable climatic regions A report by C Branton[11] recommends the crossing of Jerseys on the native cattle, and of Holsteins on the Zebu type

On the farm of the Dairy Training and Research Institute, it was hoped to carry by the end of 1964 a milking herd of 60 to 80 cows of reasonable average production, plus replacement stock and some experimental animals, on a total improved pasture area of about 40 hectares, plus silage and a little hay The present pastures are largely *Panicum maximum*, *Pennisetum purpureum*, *Brachiaria mutica*, *Alabang* x (*Dichanthium* sp), and some Pangola (*Digitaria decumbens*)

In these early stages of the dairy industry in the Philippines, it will be desirable to carry out an ecological land use survey on the lines at present under consideration One might also approach the problem from the opposite angle work out the milk requirements of a city like Manila on the basis of reasonable human nutritional standards and potential purchasing power, calculate how many animals of one type or

another (in milk, dry and young stock) would be needed to produce that milk on a year-round basis, and then bring in the ecological land-use survey to delineate the areas where this total productive livestock population could be maintained in a well-fed and healthy condition.

TAIWAN

Farmers now see the advantages of fodder crops for feeding to hogs and poultry, and are also developing grassland areas on sloping land. With the successful introduction of many tropical and subtropical grasses and legumes since 1957, many demonstrations have been established jointly by the Joint Commission on Rural Reconstruction (JCRR) and the Provisional Department of Agriculture and Forestry with the co-operation of the Hsien Government and Farmers Association Agricultural Extension workers.[98] Most have been established on relatively poor soils not suitable for crop production. As a result, over 1,000 hectares (2,500 acres) have been planted since 1958. During 1960 approximately 600 hectares (1,500 acres) were planted to improved fodder crops, chiefly Pangola grass (*Digitaria decumbens*). About 200 hectares (500 acres) was planted by paddy farmers in small plots of 0·2 of a hectare (½ acre) to 1 hectare (2·5 acres) on dryland or sloping unproductive land adjacent to their rice fields. These farmers are utilizing the forage to feed cattle and have thus added another enterprise to their business. The manure is used on rice fields to improve the organic matter status and to increase yields. This development is spreading in northern Taiwan and by 1961 over 100 farmers had purchased dairy cows. Undoubtedly this will be the nucleus of the future dairy industry on Taiwan under agroclimatic conditions intermediate between those in the Philippines and Kyushu in Japan. Economic data relating to the feasibility of including milk production in typical farming systems in Taiwan husbandry are given in Chapter X.

JAPAN

Some distinction should be drawn between the other countries taken for case studies, and the major and minor islands of Japan. Most of the countries studied are primarily agricultural and are located in tropical and sub-tropical latitudes. Japan is an industrial country, an important factor in considering the incentive created by market demand and pur-

chasing power, and much of the country has cold to sub-arctic winters and warm to subtropical summers Since 1945, something of a revolution has been taking place in Japanese agriculture, with major changes in the traditional pattern of farming ([63]) This revolution has been partly the result and partly the cause of a basic change in the eating habits of many Japanese people In common with most countries of south-east Asia, the diet has so far been predominantly fish, rice and vegetables, rapid 'Westernization', inadequate supplies of fish, and interest in modern nutritional standards have caused an increasing demand for a more varied diet including wheat bread, milk, meat, eggs and dairy produce such as butter and cheese There has consequently been a spectacular expansion of livestock production in all parts of the country Dairy factories owned and operated by three large commercial companies, Snow Brand, Morinaga and Meiji, are well distributed throughout the country The Government is promoting dairy farming by enactments such as the Agricultural Basic Law, Dairy Farming Promotion Law and other measures

It is anticipated that by 1970 the total value of the livestock output should represent one-third of the total national agricultural production and should be equivalent in value to the production of rice The demand for meat should have risen to five times its present level while milk consumption should increase from 0 1 pint per head to at least one-third of a pint daily (0 05 to 0 15 litre per day) The present dairy cattle population of some 900,000 head (almost entirely Holstein) is expected to increase to approximately 2 5 million by 1970, a high expectation since the number of productive females increases at an annual rate of about 18 to 20 per cent. But during the six-year period 1955–61, the dairy cattle population had more than doubled, while the number of farms keeping this type of animal increased by some 65 per cent, the number of dairy cattle per farm increased from 1 63 to 2 10 over the same period, and is expanding steadily

Most of these dairy cattle have been and still are fed on crop residues, on green herbage cut from the bunds and similar places, and on so much purchased concentrates that this has a marked influence on the costs of milk production The Government has, therefore, given high priority to pasture and fodder development in order to reduce the overall costs of production, and in this respect has received technical assistance from FAO during the period 1955–63 ([62]) The Central and Prefectural Governments have voted large sums of money to support the reclamation of land for pasture development on farmers' properties, on munici-

pal land, and for the so-called large-scale projects in the hill and mountain areas.

Of the three major factors of the environment, topography, climate and soils, we should probably regard topography as the most important limiting or governing factor in deciding the location and nature of pasture and fodder development as the basis of an efficient dairy industry in Japan. Only about one-sixth of the land is cultivated at present, and is the source of most of the country's plant food; what is done with the other five-sixths (and it is here where the greatest potentialities for pasture development are to be found) is of great national significance from the point of view of balanced land-use and the conservation of soil and water.

The climate is a complex pattern of regional and micro-climates, governed by degree of proximity to the seas, cold and warm, that surround the country, by latitude and elevation, and by characters of general relief such as mountain barriers, land depressions, mountain shelters and degree of exposure to north and south. The land area comes under the alternate influence of moisture-laden, warm south-eastern sea winds in summer, and of raw, cold north-western winds in winter, in fact, an alternation between subtropical and subarctic conditions, between the Pacific maritime climate with the Siberian continental climate.

It is the length of the growing period of the grasses and legumes cultivated as pastures and fodder crops that governs the whole pattern of farming and the nature of the livestock industry, and it is climate that governs that growing period. Since the duration of the growing period decides the balance between grazing and the conservation of plant growth during the growing season for the winter, it also decides the plan of the farm, the cropping system, and the methods of animal husbandry. Since most of the larger pasture development projects are in Hokkaido and at the higher elevations in Honshu, the duration and intensity of the winter period are of major significance in catering for dairy development. The large projects and the individual farms have to grow species and to adopt methods which will ensure the maximum availability of high-quality conserved fodder for the winter. The provision of grazing for the summer has to take second place to this primary demand. Further, the predominant pattern of distribution of precipitation is characterized by a summer maximum; as this frequently occurs during the haymaking season, the emphasis has to be primarily on silage for climatic as well as nutritional reasons.

In view of the irregular nature or seasonal variability of the agro-

climates of Japan, a study should be made on their nature, hazards and degree of expected variability In Hokkaido, one needs to know how frequently one may expect the early frosts in autumn which would bring the growing period to a premature end, or how frequently one may expect an abnormally dry and late spring which delays the revival or growth and the commencement of the growing or grazing season. In western Honshu and Kyushu, on the other hand, it is necessary to know the expected duration at different places of the summer period of high temperatures and drought This is when the grasses and clovers of temperate latitudes cease growth, and have to be replaced temporarily by the pasture and fodder species adapted to grow within a higher temperature range The agroclimatic conditions are largely unsuitable for the production of seeds of grasses and legumes, because of the humid conditions generally obtaining at the time of seed maturation and harvest It may be possible to find certain areas where the expectancy of reasonably favourable conditions for seed harvesting may be greater than elsewhere

The major soil types on which pasture development for dairy production is in progress or is planned are volcanic ashes of varying ages, peats, and heavy clays The deeper peats in particular are unsuitable for grazing, and here the cut-and-carry system may be technically justified, provided there is a full return of fertility to the land in the form of dung and urine or fertilizers Because of the mountainous nature of the land in which projects for dairy development are located, it may be necessary to adopt some type of stratification of pasture improvement and livestock development, in relation to altitude, distance from village or town, investment in land improvement and reclamation, distance from markets or milk factory, and potential economic return [157] There is an urgent need to evolve cheaper methods of transforming the natural types of vegetation, which are useless for dairy cattle, into high-producing pastures of British or New Zealand composition and standard If these pastures can be managed with full cognizance of the fertility cycle soil/plant/animal/soil, there is little doubt that high production of milk per hectare will be possible A situation may develop in which the producing cows are maintained in stalls or on intensive pastures in or near the farming areas, while the young and dry stock are maintained on the large-scale pastures farther away At present, pasture development is tending to get ahead of livestock numbers. It would be desirable if all the Holstein male calves that are at present sold at one week of age to be made into sausages could be reared and fattened on grass, for the

benefit of the pastures and to provide a cheaper form of beef as a profitable adjunct to the dairy industry.

CARIBBEAN AND LATIN AMERICA

PUERTO RICO

A quarter of a century ago, dairy farming in Puerto Rico was commercially insignificant but today the income from milk and dairy products is more than double the combined income from the two traditional crops, coffee and tobacco.(99) Fluid milk is the only commodity the commercial production of which has increased steadily and consistently both in quantity and in value during the past decade. Commercial dairying represents a break from the traditional pattern of plantation agriculture, from the earliest Spanish and American exploitive colonial commercialism towards a strong and independent agriculture, one of the first major productive efforts that have been made for the home market.

The dairy operator usually lives on his farm, owns or leases the land he uses, and is often engaged in the production of commodities other than fodder for his cattle. The typical dairy farm is large, requiring considerable capital investment. In 1959 more than 80 per cent of all milk sold was produced on farms where more than half the sales consisted of livestock products and where total sales per farm exceeded $20,000 per annum (Table 31).

TABLE 31

Puerto Rico. Milk sold on commercial farms by volume and value, 1959(99)

Farm type	Percentage of milk sold	ECONOMIC CLASS OF FARM Class	Sales in $	Percentage of milk sold
Livestock	81·1	I	over 20,000	80·3
Sugar-cane	15·8	II	10,000–20,000	7·5
General crops	1·9	III	7,500–10,000	1·8
Coffee	0 4	IV	5,000– 7,500	3·1
Tobacco	0·3	V	2,500– 5,000	5·0
Fruit and nuts	0·3	VI	1,200– 2,500	1·6
Minor crops	0 2	VII	500– 1,200	0 6
		VIII	150– 500	0·1
Total	100 0			100·0

Before 1910, dairying was based upon large numbers of criollo and imported Asian cattle kept for draught and the production of beef and hides Since then, the importation of high grade cattle of all the European dairy breeds has been steadily increasing, and the resultant upgrading has led to a better yield per animal After World War II, commercial dairying developed into a major agricultural industry, annual production increasing from about 130 million litres in 1946–7 to 310 million litres in 1958–9 There are five main reasons for this increase (99)

(1) The urban population has almost doubled in the last twenty years, and this growth of cities has been rapid enough to create the concentrated market necessary to support commercial dairying The role played by agriculture has steadily declined, while the number of employees on the higher pay scales in manufacturing, trade and government has greatly increased The *per caput* rates of increase for net income and milk consumption for the past decade are $1 89 and $1 88 respectively

(2) The average Puerto Rican consumes more milk each year (estimated consumption in kg per head per annum, 1957 = Guatemala 80, Nicaragua 100, Honduras 120, Venezuela 140, Cuba 141, Costa Rica 150, Puerto Rico 200) Since 1950 the percentage of total milk production reaching the urban pasteurizing plants has increased from 30 to 40, but imports have remained steady at more than $20 million annually It is not unreasonable to expect the annual consumption of dairy products to reach the U S level (707 lb per head—about 314 kg —in 1957) in another decade

(3) The Government has actively sponsored milk distribution throughout the island

(4) Pasture management and livestock breeding have increased greatly in efficiency A Government programme of artificial and live insemination was started in 1954, and special high-quality breeding stock is maintained at twenty seven stations from which families of low income producing milk at a subsistence level may buy superior dairy animals

Pasture management has greatly improved in recent years The area under 'pasture' has fallen slightly since the last decennial census (from about 800,000 to 750 000 acres) but the area under harvested fodder has increased to 70,000 acres Guinea grass (*Panicum maximum*) and Para grass (*Brachiaria mutica*) were the original grasses which were fed with sugar-cane tops (of little value in maintaining a uniform level of milk production) Now *Digitaria decumbens* (Pangola), *Pennisetum purpureum*

and *Melinis minutiflora* supplement the Guinea grass in commercial dairying. The Government 'Programme of Pasture Improvement' (1953) and 'Unified Programme for Pasture Conservation' (1960) were designed to help farmers to establish or improve high-quality pastures, with financial support for eradication of weeds, application of fertilizers, construction of fences for rotational grazing, pipes for watering livestock, and silos, wells, molasses, tanks and milking parlours. Farmers receive \$15 per acre (= \$36 per hectare) for planting the above grasses and another \$18 per acre (= \$43·2 per hectare) for planting tropical Kudzu (*Pueraria phaseoloides*). Most of the silos are concentrated on the dry south coast, where the annual drought lasts from December to April. A study of all dairy farms not classified as first-class showed that the daily output per cow was 5·8 litres on co-operating farms, compared with 3·4 litres on non-participating farms.

Mechanization has made it possible to reduce the competition for fodder from draught animals. This trend has released a vast acreage of grassland for the livestock industry, and so far the dairy industry has taken up the slack. A great deal of meat is imported from the United States mainland, and an increase in the number of animals raised for beef on the island's grassland may be expected.

Production from the dairy herd has risen sharply, and indications are that the potential has not even been approached. It appears that the island can support a much greater number of animals, while the daily yield per cow continues to increase. The dairy herd rose from 74,000 in 1940 to 96,250 in 1960, and during this same twenty-year span other cattle (exclusive of work oxen and milk cows) increased from 158,000 to 182,000. Koenig(94) predicts that the number of dairy cows in Puerto Rico could be increased to at least 275,000 head. At the same time, it is noted that at present only about one-third of the milk produced on the farms enters the commercial market.

An estimate of average daily production was 5·41 litres per cow in 1958–9, equivalent to 4,588 lb. (= 2,040 kg.) per cow per annum. This figure is close to the estimated average annual output per cow, 4,400 lb. (= 1,955 kg.), reported in a study of high-quality farms in the San Juan Dairy Belt in 1951, which then accounted for about one-quarter of the insular supply. Production of milk on licensed commercial dairies now averages between 5,400 and 7,400 lb. (= 2,400 and 3,300 kg.) per cow per annum.(99)

The system of marketing dairy products has also improved.

'In view of the favourable market conditions that exist in Puerto

Rico for dairy products, together with the great advantages in land management and animal husbandry, it is difficult to be anything but optimistic about the future of the dairy industry Dairying, being an intensive activity with a high return per acre, is compatible with a high density of population Also, it effectively supplements the cultivation of sugar-cane, still the main crop of the island. . . . The Puerto Rican dairy industry should serve as a model for other densely populated countries in the tropics that may be underdeveloped Certainly, not all such areas will qualify, for conditions favourable to dairying are many; they include, in addition to a responsive market, active governmental support in finance, education and technology Any nation or region endowed with these potentials would do well to emulate the Puerto Rican example and begin its own revolution in tropical agriculture '(99)

MEXICO

Most of the dairy farms are concentrated around the large cities such as Mexico City, Guadalajara, Monterrey and others The methods used in management in these dairy districts are in general up to date, and are based on the latest technical developments Nevertheless, there remain ample possibilities for improvement

Over the past decade there has been a gradual increase in milk production in Mexico, largely due to the establishment of dairy factories by private enterprise in rural areas away from the centres of population. The provision by these factories of a secure outlet for his milk has induced the farmer to increase the production from his herd Although there is a significant increase in production in these areas, there is still much to be done to create an efficient dairy industry Such aspects as pasture and fodder production and utilization, management of the dairy herd, and the prevention and control of animal diseases are deficient or totally absent Although the milk companies are themselves making some effort to improve this situation in their own milk supply areas, there is no doubt that a well-organized and co-ordinated extension service could do much to make farmers aware of the benefits to be derived from a change from their present traditional methods

Apart from this need for increased efficiency and intensification of the dairy industry in the districts with a secure outlet for milk, it would also be desirable to establish additional dairy factories in districts with a potential but undeveloped milk production Where the establishment of these new factories adapted to local conditions and requirements can

be combined with a programme of improved dairy husbandry conducted by the Government or the dairy companies individually or jointly, it is possible to visualize relatively rapid results leading towards greater production to meet the increasing demand for milk.

With the establishment in late 1962 of the Centro Nacional de Investigaciones Pecuaria, research on dairy animals has started as part of the work on animal research. This institution will fill a large gap in Mexican agricultural research, and will certainly play an important part in stimulating a shift in animal production, and not least in the field of dairy farming, from extensive to intensive systems of management.

The Government of Mexico/UNICEF milk powder plant at Jiquilpan has a planned daily throughput of 125,000 litres. It has been estimated that this daily production is achieved during the rainy months from June to October, but that it falls to half this quantity during the dry season. Particulars regarding the climate, natural vegetation, land tenure and livestock have been provided by Teunissen,(150) for the Jiquilpan procurement area, which is mostly within the State of Michoacan, with a small mountainous part in the State of Jalisco.

Temperatures are almost ideal for crop growth throughout the year, but the limiting factor is the well-defined pattern of rainfall with a dry season of 4 to 5 months from June to September. Climatic data are provided in Table 32 for two contrasting sites, Yurecuaro as typical of the lower part of the area, the Cienaga of Chapala at 1,500 m. above sea level, and Quitupan, a village at 2,000 m., typical of the Sierra.

The soils in the mountainous part are mainly chestnut soils and black chernozem. The soil layer is generally thin and is interspersed with stones on underlying rocks of Cretaceous period and volcanic in type. In the old lake bottom, the so-called Cienaga of Chapala, most of the soils are deposits of the Lerma River. Some parts of the Cienaga have soils with a heavy compact structure which do not absorb water quickly, crack when dry, and are difficult to work; other areas have impermeable subsoils which hinder root development and drainage, are strongly alkaline and deficient in calcium, requiring 2,500 to 3,000 kg. of gypsum per hectare; about 80 per cent of the soils in the Cienaga are more or less affected by salt—the black alkali may be improved by applications of sulphur and the correct use of irrigation water. If phosphatic and nitrogenous fertilizers are applied (there is ample potash), good fodder crops could be grown.

At altitudes from 1,650 to 2,000 m., natural pastures are found on what represents 36 per cent of the whole area. This short grass range

TABLE 32

Mexico Climatic data for contrasting sites in the Jiquilpan procurement area (15-year average, 1946–60)

	Jan.	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean of monthly average of minimum temperature in °C.													
Yurecuaro	6.9	8.3	9.9	12.1	14.9	16.3	16.3	15.9	15.8	13.5	10.8	8.8	12.4
Quitupan	7.9	8.3	10.5	12.6	14.5	16.2	15.3	14.9	14.8	12.8	10.8	8.9	12.3
Mean of monthly average of maximum temperature in °C													
Yurecuaro	25.8	27.4	29.8	31.5	32.3	30.3	27.9	28.0	27.1	27.8	27.1	25.5	28.4
Quitupan	24.0	25.8	28.2	29.8	30.3	27.5	25.5	26.0	25.7	25.7	25.2	24.1	26.4
Mean monthly rainfall in mm													
Yurecuaro	11.0	4.2	0.9	10.3	30.8	144.2	180.0	154.4	126.1	56.7	16.3	8.4	743.3
Quitupan	14.7	3.1	2.2	13.2	54.9	162.0	149.1	169.6	135.6	106.1	37.5	17.5	865.5
Mean number of days with precipitation													
Yurecuaro	2.0	0.4	0.2	1.6	5.3	21.9	20.2	18.1	13.3	7.0	2.0	1.8	92.0
Quitupan	2.0	1.0	0.5	1.9	7.5	17.4	23.3	20.9	16.5	9.3	3.4	2.3	106.0
Mean number of days with frost													
Yurecuaro	1.2	0.7	—	—	—	—	—	—	—	—	—	1.2	3.1
Quitupan	5.5	2.4	0.9	—	—	—	—	—	—	—	2.6	3.9	15.3

contains species of *Bouteloua*, *Andropogon*, *Agrostis*, *Poa* and *Trisetum*. There is considerable encroachment of mesquite (*Prosopis juliflora*, *P. velutina*) due to mismanagement of land. During the first 6 to 8 weeks after the onset of rains, the nutritive value of this grassland is reasonably high and individual animals may produce up to 6 or 7 litres of milk per day. The pastures may be said to provide grazing for about 4 to 5 months, but hardly up to the requirements of good dairy animals.

When one comes to consider the fodder potentialities of the lower elevations around the lake, land-use and tenure become predominant factors (Table 33).

TABLE 33

Mexico. Land-use in the Jiquilpan procurement area

	Total	Irrigated	Residual moisture	Dry-land	Natural pasture	Forest or unproductive
Hectares	190,220	29,560	4,312	50,462	67,980	37,906
Percentage	100	15·5	2·3	26·5	35·7	19·9

In recent decades the Mexican Government has given land to landless peasants called *ejidatarios* in a programme of agrarian reform. Much of the good land with facilities for irrigation was included in this redistribution, or these facilities were provided after the peasants had acquired the land (Table 34).

TABLE 34

Mexico. Distribution of land classes among small landowners and ejidatarios

	Total	Irrigated	Residual moisture	Dry-land	Natural pasture	Forest or unproductive
Small land-owners						
Hectares	59,585	3,075	956	17,851	28,711	8,991
Percentage	31·3	1·6	0·5	9·4	15·1	4·7
Ejidatarios						
Hectares	130,635	26,481	3,356	32,611	39,269	28,915
Percentage	68·7	13·F	1·8	17·1	20·6	15·2

The small landowners have holdings of 22·6 hectares compared with 7·9 hectares for the *ejidatarios*, but of 2,639 small landowners 1,089 have holdings of an average 51·08 hectares. Some of the *ejidatarios* have irrigated (4 to 5 hectares), some have only dryland or forest and pasture

land or a combination of both The dryland crop is maize (1,500 to 2,000 kg per hectare), with a little chickpea on the residual moisture, the crops on irrigated land are maize in summer, wheat on irrigated land in the winter (2,000 kg per ha) There are only 150 hectares of lucerne, and some fodder sorghum is grown under dryland and irrigated conditions Few of the small landowners, who also mostly own livestock, grow any fodder, the *ejidatarios* prefer to allow their few milk cows to graze irrigation and drainage ditches

The Jiquilpan procurement area forms part of a region which was once famous for its criollo cattle and its dairy industry By crossing Holstein, Brown Swiss and Zebu on to the original Spanish cattle, a mixture called *corriente* was produced, but the recent trend has been towards Holstein, to the extent that about 50 per cent of the animals have at least 75 per cent Holstein blood

The standards of feeding and management are very low As already stated the cattle remain on the natural pasture or range for 4 to 5 months of the rainy season on herbage that is relatively good for only 6 to 8 weeks of that period, with no rotational grazing nor any supplementary feeding. When growth on the pastures ceases in October/November, the cattle are moved to the cultivated fields at the lower elevations where they graze the dry cornstalks and the cover of annual weeds and grass, mostly *Cynodon dactylon* Small amounts of concentrates are given From January onwards, the animals are kept on the available dryland fields with little more than a little ground cornstalks and 0 5 to 1 kg of concentrate per day The feed situation becomes worse during April, May and June, and deaths are a common occurrence

The average daily milk yield is about 4 litres per animal falling at the end of a 240- to 270-day lactation period to 1 5 to 2 litres Most calving is in April and May, and the calf remains with the mother as long as possible Many of the calves are stunted for lack of enough or proper feed, and a heterogeneous and badly developed herd of adult animals is the result Pregnancy at the age of 11 or 12 months is the result of the continuous presence of the bulls in the herd. Diseases like brucellosis, piroplasmosis, anaplasmosis and tuberculosis are common, and internal parasites cause much damage

Much time would be needed to carry out the radical changes that are necessary in dairy husbandry in this area, since they involve not only the dairy industry, but the whole pattern of agriculture (150) A first step towards the improvement of productivity which will give comparatively

rapid though limited results would be better management of the animals and more efficient use of the fodder resources now available:

(*a*) selection of better animals and culling of the unproductive ones;
(*b*) improvement in methods of rearing young stock;
(*c*) improvement in breeding methods;
(*d*) control of diseases; and
(*e*) use of adequate and well-balanced rations based on feeds at present available.

In many villages, the social standard of the livestock owners is related to the size of their herds. It may not, therefore, be easy to convince farmers of the need to eliminate from their herds all oxen and cows over 13 or 14 years of age or all the young male animals, even though this would make more pasture and feed resources available for the milch animals.

It is estimated that an average of 6 litres per day per animal may be obtained under present conditions with improved feeding alone. A lactation of 270 days and a dry period of 150 days can be assumed (proportion of animals in milk and dry 9:5). To produce 125,000 litres per day, there would need to be about 21,000 animals in milk plus 11,500 dry, making a total of 32,500; allowing for sick animals, difficulties with pregnancy, etc., 35,000 would be a safe figure for mature animals, with young stock amounting to 25 per cent or 8,750 animals.

Even with these improvements the conditions are still far from optimal for a highly efficient and profitable dairy industry, nor is it possible to produce large quantities of milk at relatively low cost. When the dairy stock improve, feed resources should also improve, and vice versa. The ultimate objective, according to Teunissen, should be an intensive dairy industry based on high-quality fodder crops produced on the irrigated land of the Cienaga of Chapala at the lower elevation. An integration of dairy farming and arable agriculture should replace the present divorce of the two. This would result in that diversification in the pattern of agriculture which is agriculturally and economically desirable, and the replacing of the present soil-exhausting monoculture of maize and wheat by a well-designed rotation incorporating fodder crops, particularly lucerne. The growth of this crop becomes much less in the colder winter season, and at that time maize conserved as silage during the summer rains should for three months take the place of lucerne in the ration. The dairy animals should rely less upon the natural pasture in the Sierra and the crop residues, and should remain at the lower elevations throughout the year. The natural pastures may still be used during

the rainy season for the grazing of dry cows and heifers, and possibly for the keeping of beef cows for breeding

Under this system, 125,000 litres per day would be produced by 12,500 cows giving 10 litres per head per day, with a lactation of 10 months and dry period of 2 months, plus an additional 2,500 dry cows and 3,750 young females Lucerne is likely to be the most important cultivated fodder crop, giving yields of 70 tons green matter per hectare In order to calculate the area of land required to feed these numbers of animals, we have to assume that the weight of an average cow will be, say, 350 kg Its consumption would then be 8 6 kg of dry matter per day It is planned by local specialists to provide 3 kg in the form of concentrate, which leaves 5 6 kg to be supplied by the lucerne This amount of lucerne will give 1 15 kg (2 6 lb) of digestible crude protein plus 2 9 kg (6 5 lb) of starch equivalent While the starch equivalent figure is perhaps slightly high, the digestible protein figure is at least four times the normal quantity Unless the concentrate brings this more into balance, the cow would be eating too much protein which could damage the functioning of the kidneys Actually the concentrate mixture which it is proposed to use, at least the one using sorghum grain with the oil-cakes, would be supplying all the protein required for milk production, so that any more being provided by lucerne would be in excess Basing the calculations upon these considerations, it is possible to determine what proportion of the irrigable land in the Cienaga would be needed for lucerne production, plus some 600 hectares of maize to give silage during the rainy season Some economy in expenditure on concentrates would appear to be possible

Better feeding throughout the year and a better distribution of calving dates should reduce the difference between summer and winter milk production from its present ratio of two to one Much may be done in the direction of better grazing management on the natural pastures, the provision of watering places, the eradication of shrubby growth, and re-seeding and application of fertilizers It is not realistic to recommend irrigated pastures at the lower elevation, and all the efforts must therefore be directed towards the incorporation of annual and perennial fodder crops, particularly legumes, into the rotation

GUATEMALA

The Republic of Guatemala, situated between 13°40′ and 17°51′ northern latitude and from 88°45′ to 92°50′ west longitude, has a total

area of 108,889 km.^{2} and a population of about 4·0 million, increasing at about 3·8 per cent per annum. There is reputedly no country of the same size in the world which shows such differences in altitude, climate and population: from sea level to volcanoes of more than 4,000 metres, from tropical plains with local variation in rainfall from abundant to slight precipitation, to mountain areas with a winter period of several months, in which frosts are experienced, from very densely populated mountain areas to the thinly (less than 1 per km.^{2}) populated tropical plain of El Petén. (Information for this Country Study contributed by R. Hewson.)

The country can be divided into three main regions, lowland, central area and mountainous area. The lowland area is divided into three parts, the Caribbean plain, the plain of El Petén (both of which are sparsely populated and undeveloped) and the Pacific plain. The Pacific coast plain is possibly the most important agricultural area of the country. The lowland areas occupy more than 50 per cent of the country and about 10 per cent of the population live there. The central area occupies about 25 per cent of the area, with also about 25 per cent of the population. There are many farmed out lands and serious signs of erosion in these areas. Areas higher than 1,250 m. above sea level are considered to belong to the mountainous group. In general, these areas are severely dissected, and deforestation and erosion are serious problems. Though the mountainous areas occupy only about 18 per cent of the land area of the Republic, about 65 per cent of the population are located there, living by subsistence farming of small holdings.

The economy of Guatemala is based upon agriculture, the principal exports being coffee and cotton. Because of a recurrent deficit trade balance, attempts are being made to diversify from the two major export crops. Secondary industries are being established at an increasing rate, and stress is being laid on increasing livestock production to meet export needs, and the requirements of the growing population.

Economic activity has increased rapidly in Guatemala in the last few years. During 1964, for instance, there was a 7·0 per cent increase in real gross domestic production and a 9·9 per cent increase in the gross domestic income, according to preliminary estimates of the Banco de Guatemala. More than a quarter of the improvement in gross national income resulted from an improvement in export trade, especially trade in some of the export crops. Exports rose from about \$30·4 million in 1945 to about \$114·5 million in 1962. Importations also rose, from \$23·3 million in 1945 to about \$135·9 million in 1962. The latest indications,

according to preliminary data (March 1966), are that a more favourable trade balance was attained in 1965 Exports in 1965 amounted to about \$115 6 million, whilst imports were about \$108 5 million Guatemala represents a country in a very active stage of development, in which markets for livestock products are increasing rapidly

From 1946 to June 1963, international and U S Government agencies committed approximately \$200 million in economic development loans and grants to Guatemala This amount includes loans of \$18 2 million by the IBRD, \$5 3 million by IDB, \$3 9 million by the Central American Bank for Economic Integration, \$45 1 million by the U S Government Agencies, \$33 7 by the U S Bureau of Public Roads for the construction of the Interamerican Highway, and \$92 2 million in other U S grants In recent years, there has been a tremendous increase in the assistance given to Guatemala by various United Nations agencies, by other sources of bilateral assistance, and by private relief organizations

Notwithstanding, livestock development has lagged behind the surge in economic activity and the growing internal and external markets in Guatemala Of the credits offered to the farmers in Guatemala, by national banking organizations, a very small percentage has been destined for livestock development For instance, in 1964 a total of \$51 0 million agricultural credit was given Of this, \$15 5 million went to coffee, \$20 5 million went to cotton, and only \$8 5 million went to livestock. Of this, it is noteworthy that \$1 7 million was for breeding operations and \$5 4 million was for fattening operations Whilst the small amount of credit taken up by cattle farmers in Guatemala may be an effect rather than a cause, nevertheless, it is quite obvious that the low percentage of agricultural credit destined for breeding operations reflects strongly the rather disappointing results in livestock development evidenced in Guatemala

Both beef and milk as sources of animal protein are deficient in Guatemala The availability of beef on the internal market has dropped from an estimated 9 kg per head per year in 1960 to 5 kg per head in 1965 Considering that about 15 per cent of the total population live in the City of Guatemala, and the average beef consumption in the city is about 21 kg. per head per year, the low amount of beef available in the rural area is evident. It is interesting to note that in spite of the beef shortage in the country, at least 20 per cent of total beef production is exported This position has been brought about mainly by the balance of payment deficiencies noted elsewhere

The milk situation is also rather unsatisfactory. Total milk production in Guatemala is estimated at about 420,000 litres per day. With a population just over 4·0 million people, this is a mean availability of about 0·1 litres per head per day. In Guatemala City, consumption has been estimated at about 0·1 litre per head per day, and in some of the smaller towns consumption was checked to be about 0·05 litre per head per day. These figures are for fluid milk; in addition to this a large amount of imported milk powder and dairy products is consumed. With the exception of milk in Guatemala City, fluid milk consumption is entirely of raw milk produced and distributed under most unhygienic conditions.

In Guatemala City, a daily total fluid milk consumption of about 62,000 litres per day is estimated. Of this amount 18,000 litres, or about 40 per cent, are pasteurized milk of good quality. The pasteurized supply is marketed by four companies:

	Litres per day
Foremost, S. A.	10,000
La Pradera	11,500
La Modesta	3,000
Asunción Mita	3,000

One new plant, La Palma, is scheduled to commence operations in April 1966.

There are no laws in Guatemala which prohibit the sale of untreated milk, or control the sanitary facilities of the producers and distributors. Furthermore, there is no organization such as a National Milk Board, and no group advertising for milk and milk products. No school feeding or subsidized welfare feeding organization for fluid milk exists. Retail prices in general are about $0.20 to $0·22 per litre for pasteurized milk in cartons and bottles, whereas raw milk is sold on the streets from $0·15 to $0·20 per litre.

One of the big problems is that the amount of milk which is available to the pasteurizing companies does not meet demand, especially in the dry season. For about three months, a 30 per cent reduction in supply is felt, and at this time the pasteurizing plants experience great difficulty in obtaining milk supplies. It is precisely during this period that pasteurizing plants have the opportunity to expand their market, since the supply of raw milk sold in competition is reduced and more expensive. The prices paid by pasteurizing plants for milk supplies are from $0·10 to $0·14 per litre delivered to the plants.

Many areas of Guatemala are eminently suitable for dairy farming

and milk production The present picture is that much of the fluid milk produced comes from areas which are not best for such production Near Guatemala City the largest suppliers of pasteurizing plants are coffee farmers, or industrialists who have set up dairies as secondary enterprises The capital investment by such farmers has resulted in dairy operations with good livestock and with sound installations producing good quality milk Other producers are mostly small holders who keep a few poor quality cows on crop residues Another type of farmer has primarily a beef cattle operation from which a certain amount of milk is extracted Both of the latter are highly unsatisfactory producers, and most of their production is sold by raw milk vendors at lower prices than the good-quality pasteurized milk Most of the latter producers milk only once a day, and rear a calf at the same time This probably accounts for a large part of the low average yield per cow recorded in Guatemala, of about 3 litres per day

The three types of producers are located in two major areas of Guatemala The better dairy farms are concentrated around Guatemala City Here there is a long dry season but other conditions are favourable The area lies at an altitude of about 1,300 to 2,000 m , and the most common grazing species is kikuyu grass (*Pennisetum clandestinum*) The common breeds are Holstein, Brown Swiss and Jersey Many of the small holders are also located in this area

The second production areas are on the coastal plains, and the lower altitude coffee areas of South Guatemala The producers here are predominantly of the beef cattle type extracting small amounts of milk per cow once per day in order to pay recurrent costs These operations are almost entirely unsatisfactory for beef or dairy production. The calves reared are poor, owing to a deficient milk supply, and the milk sold is obtained in the corral and is of poor keeping quality The most common grass species on improved pastures in the area are pangola (*Digitaria decumbens*) and Jaragua (*Hyparrhenia rufa*) The cattle are mostly brahman and criollo crosses with Brown Swiss There has been and will continue to be an increasing tendency for milk production to be introduced into newer areas In this respect much attention is being given to the areas presently occupied by extensive coffee farms

In addition to the markets for fluid milk in Guatemala, there is an annual importation of about $2 0 million worth of dairy products, mostly powdered milk. The amounts of powdered milk imported each year for commercial sale are about 4 0 million kg. In addition, relief organizations import around 2·0 million kg powdered milk per year.

The donations are handled by the Catholic Relief Services, the CARE organization of the U S A , and are used for social welfare work, including the supplying of hospitals and schools with mostly skim powder.

Milk products in Guatemala must also take account of the general picture in all Central American countries, which will soon have a Common Market system in operation In this respect, only Costa Rica is a substantial producer of milk powder, sufficient to meet the internal requirements of the country Costa Rica also plans to set up a condensing operation. The remainder of the other Central American Common Market area (including Guatemala) import annually about $6 0 million worth of dairy products of which powder accounts for about 12 0 million kg per year There are good market possibilities to reduce this vast importation

In view of this, one plant has already been established in Guatemala to manufacture milk products, and another is in an active stage of study The projected production of both plants at capacity would not be sufficient to satisfy market demand within Guatemala The first plant resulted from an agreement between the Government of Guatemala and FAO/UNICEF in 1955 Originally this plant was designed to manufacture non-fat milk powder, butter and fluid milk There have been many difficulties, however, with this plant, and it became operational only in April 1965 The plant is built at Asuncion Mita, a valley lying close to the border with El Salvador, 150 km south-east of Guatemala The climate is hot, maximum temperature 34° C , minimum 12° C There is very little dew and a relative humidity on average of about 70 per cent The area is at about 500 m elevation There are two distinct seasons of about equal duration, and a total rainfall of about 1,100 mm The dry season is rather severe, and the original intention was to set up a complete irrigation system for the Asuncion Mita valley To date, however, only a pilot irrigated area of 450 ha has been set up In 1963, the whole project was investigated by a team of consultants, who reported that the development of the Asuncion Mita irrigation system would probably not be economically feasible, and should be deferred until the full development of the southern coastal plain had been completed

There are in the Asuncion Mita area about 15,000 head of cattle of which some 6,800 are regarded for statistical purposes as being milking animals The mean yield per cow is reported as being about 2 5 litres per cow per day The plant was in the building stage from 1956 to 1965 and equipment has been provided by UNICEF for a daily milk-drying capacity of about 30,000 litres per day In the first year's operation,

there were about ninety producers, who supplied the factory with about 8,000 litres per day The intention at Asuncion Mita was for a producer co operative to take over the operation of the plant as a commercial concern after the running in period The milk producers appear to be apathetic towards this idea, and it seems likely that the plant will require considerable Government assistance for several years to come

Much justifiable criticism of the Asuncion Mita plant has been made in Guatemala The economic fallacy that skim powder would be the major product was immediately obvious, the problem being to sell the butterfat For this reason, it was found necessary to add a canning line for the production of whole milk powder Possibly inadequate surveys and overestimates for potential interest and production by the farmers may have been made In addition, the area is dry, and in the main, soils are poor The milk plant was established before a feasibility study was completed on the irrigation proposals for the valley It seems likely that the plant will have great difficulty in achieving an economic level of production in the future The sadness of this is that the failure of the Asuncion Mita plant acts as a great deterrent to the development of dairy production in the rest of the country

The other dairy plant now under the study phase would be located at or near Retalhuleu on the Pacific coast A UN Special Fund Project studying the diversification of marginal coffee areas has strongly recommended that this plant should be established, and that a dairy development scheme be initiated for the coffee area of the south west of Guatemala There is considerable production already in the area, mostly concentrated in the lower altitude areas Surveys made in the course of the study have indicated that present production is about 18,000 litres per day, with a dry season production 30 per cent less than this figure The area in which it is intended to increase dairy development is very suited for milk production The climate there is mainly a function of altitude In the coffee areas the annual mean maximum temperatures are from 28° C to 32° C Annual mean minima are from 11° C to 20° C In the areas above 300 m elevation, rainfall averages are from 3,000 to 4,000 mm and there are normally about three months of the year with less than 100 mm rain Humidity is about 80 per cent as a mean figure The soils of the area are very fertile and there is an abundance of water

The idea would be to start the plant operating from existing sources of production, which are mainly low altitude cattle farms, and at the same time initiate dairy development in the coffee farms Coffee farms

are thought most appropriate for dairy development, since there is a great demand for organic manure by the farms, and the coffee farms are mostly large, well run and with sufficient capital reserves to purchase equipment and livestock. This plant would probably be established by the Asociación Nacional del Café, with the approval of the Government of Guatemala, as one of the means to alleviate the problems caused by over-production of coffee. The plant would be controlled by a producer co-operative company sponsored by the Asociación Nacional del Café from the start, assisted by technical staff and extension services (including an artificial insemination service) supported by the Asociación del Café. The planning of this scheme has reached an advanced stage, and it was anticipated that the plant would be in operation by the end of 1967.

In general, therefore, Guatemala presents great opportunities for dairy development. Lack of organization, extension and technical services have so far limited the speed of this development. The great increase in economic activity, the prosperity of the country, and the establishment of the Central American Common Market offer excellent market prospects. Difficulties of over-production of coffee and cotton will emphasize the role of animal husbandry, and livestock production as a means of diversification is a key feature of the Guatemalan agricultural scene.

BRAZIL

Two reports of assignments directly or indirectly related to dairy development are available. The first (July 1958 to March 1961) was intended to develop and increase the production of milk, to improve its quality and lower costs of production in the area supplying milk to the UNICEF-aided milk-drying plant at Pelotas.[53] This city has a population of about 90,000, and is situated in the centre of a rich region for the production of agricultural and livestock products. The climate is mild temperate, with an average annual temperature of about 17° C., and a fairly well distributed rainfall of 1,200 mm., with drought periods rarely lasting for more than two months, in January and February.

The absence of a reliable market has limited dairy development, but so has the isolated life of the rural people, the absence of any contact with technical personnel, and of any credit facilities for small farmers. Naturally, farming systems are most inadequate and old-fashioned. There is practically no recommendation regarding milk production that

would not mean an immediate improvement The colonos are good, rather friendly, hard-working people who get very little in return for the tedious daily routine of work They are very suspicious of outsiders, produce with complete disregard of market requirements, and react strongly against any new ideas

The new dairy plant began operations at 15,000 kg per day, and the dairy farmer was thus given the opportunity of expanding his operations to the extent that his capital and land would allow It was expected that from 1962 the total plant capacity of 60,000 kg daily would not be sufficient to absorb the production of the region, and that new plants would have to be erected.

The predominant breeds are Holsteins and Jerseys, but due to poor management the yield is only about 600 to 700 kg per lactation It appears that the animals are kept mainly on open range Species mentioned for range improvement are *Lotus corniculatus*, *Trifolium subterraneum* and *Lolium multiflorum* A local seed production industry has been established

Turning to the development of grassland and fodder resources as a basis for improving animal production in tropical north-east Brazil,[(66)] we find consideration of mixed farming and crop diversification, field demonstration for better land productivity, the intensive cultivation of green fodder under zero grazing, the importance of legumes, and greater use of concentrates and conserved fodder (hay and silage)

The dairy industry of the Nordeste is small and confined to a few milk areas, the most important being the area of Batalha (Jacare dos Homens, Pão de Açucar, major Isidro) in Alagoas State, São Bento do Una in Pernambuco, and the 'Carin Paraibano' In these dairy areas the palmas (spineless cactus) are the basis of livestock feeding, but this is far from adequate on a year-round basis, and does not provide for a correct balanced ration

If dairy production is to be economically viable, it should be concentrated near centres of processing and consumption Intensive cultivation of fodder on the zero grazing method should be preferred, in order to economize on land and reduce competition with food crops In addition, under the peculiar climatic conditions of the region, it is possible to provide better feeding throughout the year through zero grazing methods Therefore high-yielding species should be used under conditions of intensive cultivation, with adequate manure and irrigation. The production of hay and silage would make an important contribution to the feeding of dairy cattle As the small farmers lack capital, construc-

tion of silos and other equipment may best be done with the help of co-operatives.

It is desirable to reduce wherever possible the use of cotton-seed cake in favour of feeds produced locally. If the dairy industry is to be expanded adequately to meet the nutritional demands of the people, it must be less dependent upon supplies of concentrates over which it has no control. Moreover, the supply of torta de algodão (cotton-seed cake) mainly from Ceará will soon become insufficient and certainly uneconomic.

It is important that the programme of dairy development should be directed also at the small farmers of the agreste in such a way that the correct integration of livestock with food and fodder crops may become an established farming system associated with the full utilization of animal manure. These changes are essential to restore soil fertility in this densely populated area, and to increase the yield of the adapted food crops.

CHILE

The average annual consumption of milk per head of population is 90 litres, considered to be a relatively high figure for a population with a low standard of living and purchasing power.([78]) According to the National Development Plan, this consumption should increase to 120 litres per head in 1972.

Milk for fluid consumption is produced mainly from the areas within 150 to 200 kilometers of the large urban centres of Santiago, Valparaiso and Concepcion (total population about 3 million). As the winter-rainfall climate of these areas is characterized by six to eight months of complete drought, irrigation by water from snow-fed rivers is widely practised. Milk for industrial purposes (manufacture of dairy products) is also produced to some extent on irrigated land, but more extensively in the high rainfall area of the Central Valley, between 38° and 41° Lat. South.

The province of Nuble is in the central-southern zone of Chile, Lat. 36°19′, Long. 72°02′ (position of capital of province, Chillan). The region has a warm temperate climate with distinct wet and dry seasons; zones with similar climates in North America are Portland (Oregon) and Vancouver (British Columbia). There are five distinct regions in the province:

(1) Coastal, mainly rolling country;

(2) Coastal Mountain;
(3) Central Valley, flat and mostly irrigated, where most of the intensive agriculture is carried out;
(4) Foothills of Andes, and
(5) High mountain region of Andes.

The areas under the different land-use classes are (in hectares): arable 557,000, natural pastures 190,000, bush 198,000, secondary regrowth 136,000, and forest 30,000 The area under irrigation is 93,000 hectares, mostly under cereals, maize, sugar-beet and sown or improved pastures Most of the area under pastures is composed of very poor native species with a short growing season in spring and severely affected by summer drought and heavy winter frosts The main components are *Festuca acanthophylla*, *Poterium sanguisorba* and species of *Erodium*, *Plantago*, *Lolium*, *Avena*, *Euphorbia*, *Lupinus* and *Raphanus*. Improved pastures have been established with *Trifolium pratense*, *T. repens* (including Ladino), *T subterraneum*, *T incarnatum*, *Lolium perenne*, *L italicum*, *Medicago sativa* (Caliverde) and *Festuca pratensis* (Kentucky 31) Climate still causes serious limitations in pasture growth, the area of improved pasture is very small but is increasing rapidly.

The total number of cattle is 136,000, of this total 60,000 are cows, and one third of that figure (20,000) dairy cows Most of the cows are European-type Holstein Friesian, followed in numbers by American-type Holstein Friesian, German Red and White, Dairy Shorthorn and local native animals with some Friesian blood Artificial insemination is provided to 79 dairies, 2,700 cows per year or 13 5 per cent of the total population Shortage of qualified staff is the factor limiting this work.

TABLE 35

Chile Size of farms in Nuble province (20,670 farms in the hands of 15,150 owners)

Farm size (in hectares)	Number of farms
1– 20	10,138
20– 100	3,488
100– 250	1,143
250–1,000	175
1,000–2,000	144
2,000–5,000	47
over 5,000	25

The last two groups have very large unproductive areas of land. Current studies of Land Reform are devoted to the solution of the problem of land ownership on the basis of rational and economic criteria.

Improvements in feeding practices have not kept in step with improvements in breeding. In more intensive and semi-intensive enterprises, the feeding in the summer season is based almost entirely upon the grazing of both natural and sown or improved pastures. The animals remain on the pasture night and day, and come to the milking shed twice a day for milking. During winter, animals are usually kept in the shed during the night; as there is virtually no grass on the pastures, feeding has to be based upon varying amounts of hay, silage, sugar-beet leaves and tops, green oats, wheat straw and some concentrates. Hay is of natural grass cut too late and therefore of low nutritive value. Silage is made from maize, grass and sugar-beet leaves. Hay and silage, green oats, sugar-beet leaves and tops and concentrate are used only in the larger dairy farms, not in small or seasonal dairy farms.

Sugar-beet has become a very popular crop giving 30 to 40 tons per hectare; it is a valuable winter feed but requires to be supplemented with adequate amounts of calcium, and the high content of oxalic acid must also be considered. There is an increased interest in concentrates in the feeding of dairy cows, but most farmers find them too expensive to be economic. Sugar-beet pulp may be used to some extent.

TABLE 36

Chile. Throughput of Nuble Co-operative

Year	Litres
1957	980,284
1958	1,205,703
1959	2,643,793
1960	4,302,685
1961	9,066,535
1962	9,933,498
1963	12,749,720

It receives milk from 192 dairy farms or members, from distances of 76 kilometers south and 95 kilometers north of Chillan. The monthly average received at the plant in 1963 was 1,064,560 litres, ranging from 1,742,689 litres in December to 668,322 litres in July.

Factors limiting development of the dairy industry include the Government policy with regard to prices, loans and imports of powdered

milk The price is fixed for political reasons because of the influence this has upon the cost of living, this is having an adverse effect upon development and farmers are at the moment tending to change to other forms of production Loans are difficult to obtain because of the administrative procedures, and the delay in becoming effective, readjustment of loans creates further difficulties because of the serious inflation Imports of powdered milk from U S A and other countries may help to meet the national deficit but they involve large amounts of foreign exchange Being subsidized it is impossible for the local product to compete.

TABLE 37

Chile Chillan—summary of records from thirty three dairy farms, 1963

	Litres	
Annual production	4,397,873	
Average monthly production	365,489	
Average daily production	12,216	
Month of highest production—December	554,179	
Month of lowest production—June	271 918	
Percentage of cows in milk to total		62 9
Annual average number of cows in milk		1,330
Annual average number of cows		2,112
Daily average production per cow in milk	9 1	
Daily average production per total cows	5 7	

Climate is also a limiting factor because of the dry summer season and very cold winter The condition of the cattle on the poor natural pastures becomes very low in the winter There is great scope for pasture improvement and better utilization and a need for a better standard of grazing management Nutritional deficiencies affect the development of improved animals Animal health is important in relation to the very poor health of the dairy animals in the winter

The local staff state that it is necessary to make a thorough study of all the problems related to the dairy industry in Nuble province, particularly livestock improvement, animal health, size and type of farm units, and every aspect of pasture and fodder development

AFRICA SOUTH OF THE SAHARA

GAMBIA

An assignment was conducted from October 1957 to September 1958, to review in particular the existing practices in animal husbandry with a view to their improvement and integration in a system of mixed farming, and also the local fodder resources and the possibility of introducing drought-resistant species. The report([11]) thus contains much information directly in line with the main thesis of the present publication. Workers in other West African countries along the fringe of the Sahara will be able to decide whether the conclusions made and techniques recommended for Gambia may apply to a wider area.

Gambia is a narrow enclave 200 miles long by 13 to 30 miles wide, on both sides of the Gambia River. Of the total area of 2,561,000 acres, some 1,767,000 acres are considered as potential arable land. The human population is about 278,000. The cattle population (1958 Census) is 143,000 (32,881 under 2 years, 19,466 bulls and castrated males, 90,368 cows over 2 years); thus there are 5·6 head per 100 acres of total area or 8·1 head per 100 acres of potential arable land. In addition there are 50,000 sheep, 75,000 goats, 4,300 donkeys, 200 horses and 227,000 poultry.

The climate is semi-arid, with a short rainy season starting in June–July and ending during October. Average rainfall is about 42 inches, but there is a wide annual variation. The rainfall is erratic and unevenly distributed, beginning with violent storms and heavy showers followed by a spell of one to three weeks of drought before a period of more even rainfall in August and September.

The principal upland crops are coos (several varieties of Guinea corn and millet), groundnuts and findo (*Digitaria exilis*), occasionally cowpeas (interplanted in coos), and maize, the latter as a rule in a fenced part of the compound.

The attitude towards cattle husbandry varies very considerably among the various tribes inhabiting the Gambia. The Fullah are the principal cattle-owning tribe. There appears to be an almost mystical association between these people and their cattle which has existed from time immemorial and which does not appear among any of the other tribes. The largest tribe, the Mandinka, has not been traditionally accustomed to keeping cattle, but this attitude is now changing. Many Mandinka own

herds which are tended by Fullah herdsmen or even by men of their own tribe The inferior status of cattle ownership and management among the Mandinka is reflected in the poor fertility of their cultivated land The Wolof do not dislike cattle husbandry, but many of the Jola and Serahuli employ Fullah herdsmen to tend their cattle Cattle are kept in herds (some 3,000 in number) to the majority of which several cattle owners contribute Investment is usually in cows and there is some disposal of male animals (proportion of males and females over two years of age 1 4 6) The ownership of cattle is, however, an indication of social standing and is often valued as such, irrespective of the actual worth of the animals

The farming unit in the Gambia is the family compound, worked by the compound owner, his mother, possibly a brother, and the wives and children According to information obtained at the end of 1957, there were 26,329 such compounds in the Protectorate It can therefore be assumed that there is an average of 5 5 head of cattle per farming family If it is assumed that only 20 per cent of the 1,767,000 acres of potential arable land is cultivated annually, the average area of cultivation in a compound is about 13 5 acres which have to maintain not only the farmer and his family, but must contribute towards the maintenance of the average figure of 5 5 head of cattle These, however, obtain much of their subsistence from uncultivated land and swamps The local Gambia cattle of the N'Dama type are well adapted to the environment, provide good beef carcass, and are docile and suitable for draught. Their milk yield, though small, is sufficient to rear a calf and to provide some surplus for human consumption It may be possible to select superior animals capable of a higher milk yield while retaining their other advantages

Since the recommendations made in the Report([41]) doubtless apply to other countries in the region, those relating to the terms of the assignment are quoted

> A systematic soil survey along the Gambia River and its principal tributaries should be carried out Lines should be taken at intervals and approximately at right angles to the river so that they intersect the principal soil belts Soil samples should be taken at intervals along these lines
>
> An experimental programme should be designed to ascertain the most suitable crop rotations for Gambian conditions The rotation should include at least one leguminous or grass-legume fodder crop The value of fodder and shelter trees should be investigated All planting should be carried out on the contour

Investigations should be carried out to discover the most efficient means of conserving and distributing animal manure.

Every effort should be made to ensure that crop residues, and in particular cereal stovers and groundnut tops, should be fully utilized as animal feeds. Experiments should be initiated with leafy varieties of these crops with the aim of obtaining the maximum total benefit from the crop.

The advisability should be considered of abandoning rice monoculture on *banto faro* land and adopting in its place either the leguminous fodder crop or a rice-legume rotation.

Full use should be made of the brans and polishings of coos and rice for feeding to livestock.

Reference should be made to the existing aerial land use maps as an aid to determining the total areas under various crops, the residues of which could be utilized for livestock feeding.

A number of herds of cattle owned by intelligent and progressive Fullah should be selected as cattle improvement centres. The cows in these herds should be divided into three groups as good, medium and poor milk producers. Breeding bulls should be selected from the progeny of the good producers and all bulls derived from the other groups discarded. The female progeny of the poor-producing group should be discarded.

For the cattle improvement herds, and eventually for all herds, a definite breeding season should be introduced, so that additional advantage can be taken of feeding stuffs when they are available in good supply.

The N'Dama cattle imported from Sierra Leone in 1955 should be distributed as follows: The cows with two bulls should be used for pure breeding in a Department of Agriculture herd, where their productive ability would be compared with that of a similar herd of indigenous cattle. The remaining bulls should be sent to three or four herds in an isolated village in the Kombos. If the progeny of these bulls prove to be superior to the indigenous cattle, an upgrading programme should be initiated.

For the purpose of providing milk to Bathurst, the introduction of European milk cattle for crossbreeding to the local stock should be considered, on the assumption that the crossbred cattle would be maintained in well-managed Government or private herds and not distributed indiscriminately. It is suggested that the Yundum Research Station would be a suitable site for this crossbreeding work.

The development of farmers' co operative societies should be encouraged with the special purpose of relieving the Gambian farmers of the necessity of falling into debt to traders and moneylenders, particularly during the rainy season These co-operative societies should initially be confined to the marketing of farm produce and the acquisition of farm implements, etc At a later stage measures for the provision of agricultural credit should be considered

It is essential to the proper development of Gambian agriculture that a comprehensive system of all weather roads should be established

It is recommended that ox ploughing should be favoured rather than tractor ploughing as an alternative to the use of hand implements The fostering of ox ploughing will encourage the farmer to maintain his animals on his own holding rather than committing them to a communal herd, thus bringing him animal products, such as milk and meat, in addition to the benefit to his crops through animal manure

Every effort should be made to discourage the practice of the communal herding of livestock, which results in the depletion, in terms of plant nutrients, of the land of the village to the benefit of that of the herdmaster on which the cattle are kept at night.

Water points should be established to provide access to the considerable areas of grazing which are at present unused

A comprehensive cattle census should be carried out at regular intervals so as to give a sound statistical basis for the development of the animal production programme

ETHIOPIA

The agricultural area lies on the high plateau between 2,000 to 3,000 m with a productive soil and adequate rainfall of 1,200 to 1,800 mm In spite of latent productivity, the agricultural economy is not well developed and meets only the needs of the peasants for self-sufficiency plus the production of a few cash crops Traditional, primitive techniques with the use of century-old types of implements continue The land is mainly in large, private properties The staple cereal, *Eragrostis tef*, is grown at high altitudes and wheat, barley and green sorghum at altitudes over 3,000 m.

The country is rich in livestock, but this resource is scarcely exploited. According to a 1962 estimate, there were then 25 million cattle, 24 mil-

lion sheep and 18 million goats, a total three times that of the human population. In addition, there are several million donkeys, mules, horses and camels. Livestock is a good source of income, providing hides, sheepskins and goatskins and the recent establishment of a National Livestock and Meat Board has led to the export of frozen and canned meats.

The improvement of livestock should be among the primary measures for the economic development of the country, as this could provide a most important source of growth of the national product and completely change the inefficient and tradition-bound economy. It is difficult to estimate milk production accurately, but it was roughly estimated in 1960 to be about 900 million litres or 45 litres per head of population per year. The average milk production per cow is about 1 or 2 litres per day, although yields from the animals of the nomadic tribes which use milk as food probably average 3 to 4 litres. About half the milk is consumed fresh on farms, largely by children, and certain quantities are marketed in the cities in the form of liquid milk, butter and cheese. The remainder is fed to livestock on farms or wasted.

There are two existing milk plants in the region of Eritrea, namely, the milk plant in Asmara, which is run privately by Italians, and the most modern farm at Elaboret, 50 miles north of Asmara, established by Casciani and de Nadi. This farm is primarily concerned with growing citrus, but a few years ago 600 cows, mostly Friesian and Ayrshire, were imported from Kenya, primarily to supply organic manure for the soil, with milk as a by-product. These cows now produce about 4,000 to 5,000 litres per day. The products of both these dairies are very expensive and quite out of the reach of the lower income groups.

The development of the Shola Ber Dairy at Addis Ababa is a particularly interesting example of the growth of a milk plant in successive stages from a pilot project to a modern milk processing plant in a developing country without previous experience in the dairy industry. The step-by step development of this milk scheme reflects the efforts of domestic endeavour assisted by UNICEF/FAO. This dairy is supplied with milk from one Government and one Imperial farm. The plant itself is located on the Shola farm of 75 hectares on the outskirts of Addis Ababa, which has 300 cows of which 120 are good European milch animals. The production of the farm is, however, low.

It is not known how many cows are crowded into the city stables in Addis Ababa, but the area around the city on the highlands is densely populated with livestock, as climate and soil are favourable for this type

of development Cattle are almost exclusively of the Zebu type, but their number and milk production are not known They live mostly on natural pastures, where year round grazing is possible, and there are no serious problems of water supply, even during the dry season Productivity of the animals is, however, very low, mainly due to the breed and to the inadequate supply of fodder on the overgrazed pastures A great deal of hay is transported into Addis Ababa to be sold to the horse and cow stables, instead of its being used on the farms themselves

KENYA

Over two thirds of the country has less than 750 mm rain per annum and grazing is the only possible type of land use Grain and other crops are grown in the highlands and in Nyanza Province On the coast the monsoon season is from April to July, and the highlands have two rainy periods, March to May and October to December African peasant agriculture consists largely of the subsistence crops, maize, millets, sorghum, plantains and cassava The modernized agriculture of the European settlers was developed in the areas with sufficient rainfall in the highlands, and is concentrated primarily on livestock with the cash crops, coffee, tea, cotton, sisal, etc

It is estimated that there are 7 million head of cattle, a large population of sheep and goats, and 250,000 camels Milk yields are extremely low According to a recent estimate, 3 million mature females of indigenous origin produce 225 million litres per annum and this output equals that from only 320,000 graded female stock of European breeds The total milk production in Kenya is estimated at about 440,000 metric tons

With the present rate of growth of population, the grazing area is becoming insufficient and has seriously deteriorated, so that symptoms of protein malnutrition and kwashiorkor have developed, even among the families owning livestock The shortage of animal protein in the country as a whole, however, is said to be primarily a problem of low purchasing power and distribution

Quite different conditions obtain among European livestock in the highlands, which is the basis of the Kenya dairy industry This has been developed over the past forty years and dairy farmers have combined to form the Kenya Co-operative Creameries, Ltd At the present period of political transition when about one third of the European farmers have left Kenya, a reduction of the national dairy herd and of total milk output is noticeable In the mixed farmland area of 3 million acres,

1 million acres have already changed hands. Some of the large farms have been broken up by the Settlement Scheme into small farms of 7 to 8 acres. More recently, most farms have been taken over by the newly established farm co-operatives, without fragmentation into small holdings.

According to the 1960–3 Census, the national registered dairy herd declined from 417,000 to 332,000 head, the decline being mostly in heifers and heifer calves which were widely slaughtered at the time of change of ownership. The production of milk for organized markets declined by 6 per cent between July 1963 and July 1964, while in the previous year it had fallen by 3·7 per cent. It is expected that the transitional period will pass in two years, and that milk production may then recover. The Government of Kenya is making all possible efforts to prevent a further decline in livestock development. Cattle could become the backbone of agriculture, since 80 per cent of the available land is suitable for dairy farming and beef ranching. An official of the Kenya Dairy Board has stated that 'for the next six or seven years upwards of 65 per cent of the mixed farming section of the agricultural industry economy is going to be derived from dairy farming and beef ranching'. The Government plans to expand milk production considerably, both for the internal market and foreign trade.

MADAGASCAR

The International Dairy Federation has issued a questionnaire on the production, collection, transport, processing and distribution of milk and dairy products in tropical countries. A copy of the reply relating to the dairy industry in Madagascar has been provided by the Director of the Bureau Central Laitier, Roger Armaing,(3) at the request of M. J. Pagot of the Institut d'Elevage et de Médecine vétérinaire des Pays tropicaux, Alfort, Seine, France.

The zone of milk production corresponds approximately to the region called the High Plateaux, on the central axis Tananarive–Fianarantsoa, with two main concentrations, the more important being within a radius of 30 to 40 km. around Tananarive, the other being on the axis Antsirabe, Ambositra, Fianarantsoa. There are also other centres of production in the region of Lac Itasy-Saky, around Lake Alaotra, and around the main towns (Diego-Suarez, Tamatave Tulear) where urban demand has stimulated livestock farmers to some small extent to take up milk production.

The agroclimatic conditions in the region of production are shown in Table 38 As the average altitude of the High Plateaux is around 1,100 m , the climate is relatively temperate in contrast with the warm, humid climate of the west coast There are two clearly distinct seasons on the High Plateaux, the southern hemisphere summer from November to April, with abundant rainfall in the form of violent storms, and the southern hemisphere winter from May to October, colder and above all drier with a marked cessation of growth The latter season is the period when the livestock suffer much from lack of feed

TABLE 38

Madagascar Meteorological data for the milk-producing areas

Areas and localities	TEMPERATURES IN °C Max	Min	Mean	Average rainfall in mm
Tananarive area				
Tananarive	22 7	12 4	17 6	1,271
Arivonimamo	23 7	11 8	17 8	1,338
Antsirabe-Fianarantsoa axis				
Antsirabe	23 2	10 5	16 9	1,442 3
Ambositra	23 4	12 4	17 9	1,490 2
Fianarantsoa	23 7	19 8	21 7	1,004
Alaotra area				
Ambohitsilaozana	26 5	14 8	20 7	1,149 5
Other areas				
Diego-Suarez	31 1	22 9	27 0	885 9
Tamatave	27 5	20 9	24 2	3,566 4
Tulear	29 8	18 1	24 0	352 3
Majunga	31 7	22 2	27 0	1,525·0

In practice, only the Zebu is used for milk production In the south of the Island (Androy and Mahafaly) there are about 230,000 goats and 200,000 sheep, but they are kept only for the production of mohair and wool There are about 8 million head of Zebu with cows in a proportion of 30 per cent In addition, there is around Tananarive and on the eastern border of the Plateaux a nucleus of pure and more especially crossbred Normandy and Friesian animals numbering about 15,000 to 20,000 in all These are in effect the only animals used for milk production Apart from three or four livestock farms run by Europeans and which are of negligible importance in the market, since they produce

Chapter XIII

SURVEY, ANALYSIS AND ACTION

Definition of Targets

Those who are responsible for the planning of dairy development on a national, regional or local basis may approach the problem from two contrasting directions They may take the information collected by a survey of a procurement area or areas and estimate what the actual production of milk is at the time of survey and to what level it might be expected to increase following the establishment of a regular market and the introduction of improvements in animal husbandry and breeding, grassland management, fodder agronomy, and the correct use of the potential feeds and fodders in well-balanced rations Alternatively, a calculation may be made of the reasonable nutritional requirements in terms of litres of milk per day of the urban and rural populations in the area concerned, one may then try to discover how fully and how rapidly that target might be achieved by introducing dairy farming into the pattern of land use and farming systems within a specified radius of the milk factory and its satellite chilling and collecting centres

In brief, one expresses on the basis of a livestock survey the total number of productive bovines of a given yield per lactation that are needed to provide the daily planned input of the milk factory The specialist in animal nutrition then calculates the individual requirements for maintenance of the types and breeds of animals concerned, whether in milk, dry or growing, in relation to their weight, and also the production ration in relation to their estimated milk yield These individual requirements are multiplied by the total number of the productive bovine population to obtain the bulk requirements of feeds, fodders and concentrates The agronomist then states the average yields per unit area to be expected in that region, and so we come to the expression of litres per day input into a milk factory in terms of the total number of acres or hectares of land needed to produce that milk When these requirements are equated with the available and potential resources, it will generally be seen that the achievement of the targets in

terms of animals and land must become the objective of a vigorous programme of action directed to all aspects of crop and livestock production and improvement. A detailed study of this type has been presented by R. O. Whyte and M. L. Mathur in their companion book, *The Planning of Milk Production in India*.(168) The methods of calculating the productive bovine population, and also the feed and fodder requirements for the total and the productive bovine population are discussed before targets are presented in relation to national milk production targets, milk plants of varying capacity, and new industrial communities with their higher-than-average purchasing power.

Information is then presented regarding the present availability of feed and fodder resources for the dairy industry in acute competition with draught animals and poultry, particularly as far as concentrates are concerned. Whyte and Mathur discuss surveys of resources by different techniques and at various levels of intensity, e.g. milk procurement areas, an Indian State (Bihar),(169) a sample survey conducted by the Indian Institute of Agricultural Research Statistics, an animal nutrition survey, and surveys of conditions in Key Village Projects or Intensive Cattle Development Projects.(170) The book concludes with a detailed analysis of selected milk schemes in India.

Too often milk processing plants are constructed in areas where the opportunities for milk production have been inadequately investigated and where the essential surveys of environment and of animal husbandry and fodder production have not been conducted by field officers. Even for established plants, the problem of expansion is certain to arise; it is desirable to know to what extent this may be feasible, and what action would be necessary to expedite the development. By applying the relevant facts and principles to a wide variety of habitats, mainly in the tropics and subtropics, it becomes possible to define with a reasonable degree of accuracy the agricultural and livestock targets which must be attained if a milk factory is to operate to its full or economic capacity.

To obtain an expression of litres input of a milk factory in terms of numbers of bovines and hectares needed to produce that milk, the agricultural and livestock targets may be expressed as follows:

(*a*) the total productive bovine population (in milk, dry and growing) that is required to provide a sufficient percentage of animals in milk at any one time to produce a given quantity of milk per day;

(*b*) the total amounts of the locally available or potential fodders, feeds and grazing needed to feed this total livestock population at all periods of the year; and

(c) the area of farm or other land needed to produce these feeds, fodders and grazing, taking into consideration the average local standards of farming and the average yields of the fodder crops or the carrying capacity of the grazing land

It is necessary to consider the potentialities for improvement of the soil fertility, the water resources, the fodder plants, and the species in the natural vegetation, and finally the livestock, their productivity, adaptability, possibility of change in feeding and management, improvement of situation regarding diseases and parasites, breeding and introduction of more productive animals Fodder improvement and livestock improvement go hand in hand, if the fodder is improved, better animals are needed to provide an adequate return on the greater investment and cost of production, if the animal is improved, it is necessary to provide a higher plane of nutrition so that it may express its potentialities in a higher milk yield

Calculations designed to define the agricultural and livestock targets have been made for India, where the productive bovine population, its requirements of concentrates and green and dry fodders, and the acreage of land that is needed to produce the green fodder, have been expressed (Table 39) in relation to five levels of milk production as follows

Million litres per day	
1	Estimated throughput of milk plants in operation in India in 1965
3	Planned initial throughput of all milk plants in public sector in operation or under construction in 1965
50	Total milk production in India, based upon estimates made in the Union Ministry of Food and Agriculture in connection with the Key Village Programme (calculation made by multiplying number of buffaloes and cows in milk by accepted average milk yields gives a different figure—30 million litres per day, see also Table 29)
80	Amount required to meet the objective of 0 17 kg or 6 ounces per head per day of total human population, a Government of India target
130	Amount required to meet the objective of 0 25 kg or 10 ounces per head per day, the figure suggested in 1944 by the Nutrition Advisory Committee of the Indian (then Imperial) Council of Medical Research

Table 39

India. Productive bovine population of varying performance, feed and fodder requirements per annum, the acreage required, for the production of milk to meet five all-India targets

Throughput in litres per day	Performance of the milch animals in litres per lactation	Productive Bovine Population (In Thousands)		Concentrate In Thousand Tons	Green Fodder		Dry Fodder		
		in milk	Total Productive Bovines		Thousand Tons	Thousand Acres	Thousand Tons	Thousand Acres when one crop is taken per year	Thousand Acres when two crops are taken per year
1,000,000	250	1,600	6,400	2,080	19,200	1,920	19,200	12,800	6,400
	500	800	3,200	1,120	11,200	1,120	9,920	6,613	3,306
	1,000	400	1,600	640	6,400	640	5,120	3,413	1,707
	1,500	267	1,067	533	4,532	453	3,466	2,311	1,156
	2,000	200	800	480	3,600	360	2,640	1,760	880
	2,500	160	640	416	2,880	288	2,112	1,408	704
3,000,000	250	4,800	19,200	6,240	57,600	5,760	57,600	38,400	19,200
	500	2,400	9,600	3,360	33,600	3,360	29,760	19,839	9,920
	1,000	1,200	4,800	1,920	19,200	1,920	15,360	10,239	5,140
	1,500	800	3,200	1,600	13,596	1,359	10,398	6,933	3,467
	2,000	600	2,400	1,440	10,800	1,080	7,920	5,280	2,640
	2,500	480	1,920	1,248	8,640	864	6,336	4,224	2,112
50,000,000	250	80,000	320,000	104,000	960,000	96,000	960,000	640,000	320,000
	500	40,000	160,000	56,000	560,000	56,000	496,000	330,650	165,326
	1,000	20,000	80,000	32,000	320,000	32,000	256,000	170,600	85,325
	1,500	13,333	53,333	26,664	226,600	22,660	173,300	115,550	57,775
	2,000	10,000	40,000	24,000	180,000	18,000	132,000	88,000	44,000
	2,500	8,000	32,000	20,800	144,000	14,000	105,600	70,400	35,200
80,000,000	250	128,000	512,000	166,400	1,536,000	153,600	1,536,000	1,024,000	512,000
	500	64,000	256,000	89,600	896,000	89,600	793,000	529,040	264,520
	1,000	32,000	128,000	51,200	512,000	51,200	409,600	273,040	136,520
	1,500	21,360	85,360	42,640	362,560	36,256	277,280	184,880	92,440
	2,000	16,000	64,000	38,400	288,000	28,800	211,200	140,800	70,400
	2,500	12,800	51,200	33,280	230,400	23,040	168,960	112,640	56,320
130,000,000	250	208,000	832,000	270,400	2,496,000	249,600	2,496,000	1,664,000	832,000
	500	104,000	416,000	145,600	1,456,000	145,600	1,289,000	859,690	429,845
	1,000	52,000	208,000	83,200	832,000	83,200	865,600	443,690	221,845
	1,500	34,639	138,693	69,304	589,160	58,916	450,580	300,430	1,500,216
	2,000	26,000	104,000	62,400	468,000	46,800	343,200	228,800	114,400
	2,500	20,800	83,200	54,080	374,400	37,440	274,560	183,040	91,520

It must be recognized that the figures of 50, 80 and 130 million litres per day relate to All-India production, whereas the first two figures represent that percentage of the milk produced in a procurement area that a new milk plant may expect to collect A Welle, formerly FAO Dairy Economist in India, has estimated that milk plants may generally expect to collect initially about 40 per cent of the total milk produced in their rural procurement area (excluding urban producers), that 30 per cent would continue to be sold through middlemen or in other ways, and that 30 per cent would remain in the villages for domestic consumption A survey in the Kaira District in Gujarat showed the same figure for the amount retained in the village Obviously these percentages are only rough estimates, and the proportions will change after the establishment of an assured market and when a reasonable price is paid regularly to the producer Some milk sales may be transferred progressively from the middlemen to the milk scheme Less milk may be kept in the villages, which is not an entirely desirable result Be that as it may, it is reasonable to estimate that, under average Indian conditions, the total amount of production involved under the first two heads above would be 2,500,000 and 7,500,000 litres per day respectively But again, these totals relate only to milk procurement areas, which do not by any means cover the whole milk producing area of the country

Surveys of Actual and Potential Production

Three phases may be recognized in the early history of a milk scheme, when it is a question of (i) estimating the actual and potential production of milk within the collecting radius of a milk factory, chilling centre or collecting point, and (ii) deciding what may be done to achieve the targets of daily throughput that are set These phases are

(*a*) the time of the original assessment or survey of an area in which it is proposed to establish a milk processing factory,

(*b*) the period between the agreement to establish a milk processing factory and the date that collection in rural areas begins, and

(*c*) the period after collection has begun and the economic stimulus of a regular market and frequent cash payments to producers has begun to operate

No one concerned with the production phases of dairy development, with all the agricultural and animal husbandry aspects that operate in the stages 'up to the bucket', can feel satisfied with the scope and degree of detail of the surveys carried out to date This situation might be

improved in two directions. It should be possible to conduct a more thorough pre-investment survey of the production phases even in the short time that is usually available. It is also desirable to make recommendations for a more detailed survey requiring more time to complete, one which would be undertaken by the national authorities according to their capabilities, to provide a basis for planning an action programme for the rapid stimulation of production by all possible means.

One must be careful not to attempt too much or expect too much from rapid reconnaissance surveys. Many answers to the points in a questionnaire may be meaningless because the surveyor did not like to turn in a partially blank form, or the farmer did not like to admit that he kept no records and that he did not really know the composition or performance of his herd from that particular angle. The headman of a village will usually exaggerate numbers of good cattle and their productivity when it is known that the surveyors are going to adjacent villages as well. Government statistics do not always give quite the type of information required in a milk potentiality survey. For this reason, the initial rapid survey has to be followed by a detailed house-to-house and cow-to-cow survey if the basic data are to be available for the planning and financing of development.

The surveys carried out in the Hyderabad/Vijayawada Integrated Project in Andhra Pradesh, India, were found to be well conceived and executed. In the Hyderabad milk procurement area, sixteen persons (vaccinators and veterinary assistants) operated in teams of four. Of the 240 villages in the Hyderabad District, 94 were surveyed along four main roads during September and October 1959. The teams interviewed individual farmers and also checked the flow of milk into the twin cities of Hyderabad and Secunderabad from various directions, counting the cans on cycles, buses and trains. These road checks confirmed the results of the village surveys, namely, that it is reasonable to expect to be able to collect 25,000 litres per day along the four main roads up to 30 miles from the city. The fact that the pilot factory at Rajendranagar has been receiving a daily average of about 7,000 litres from only part of the area surveyed is regarded as further confirmation of the potential input.

In the Vijayawada milk procurement area, a team of twenty surveyors comprised the Project Supervisor, three veterinarians and sixteen enumerators. This team has operated since 1959 and is still continuing with re-checking and elaboration of data. The enumerators lived in the villages, interviewed every farmer, counted his animals, and noted the production from each animal. They also recorded the current utilization

for (*a*) home consumption, (*b*) local manufacture of products, and (*c*) sale out of the village Record books were kept for every village of the 1,386 villages covered

To assess the correctness of the statistics obtained by oral survey, actual milk recording was undertaken in 10 per cent of the villages covered by the oral survey These villages are selected on the basis of livestock population, milk potentiality, transport facilities and degree of co-operation of the farmers A minimum of 10 per cent of the total households in the selected villages is covered, more if the local co operation is encouraging Fat testing is also done

For the actual recording, two enumerators work together, and must be present before milking starts, to record the milk yield in both the morning and evening, and to take samples for the fat test in the morning The fat test is done at a central place, partly to demonstrate to the farmers the standard upon which the future pricing pattern will be based Three enumerators are charged with the recording of lactation yields, 108 buffaloes being taken for this The enumerators work each at one of three centres, and they have to record the milk yield of each animal once a week and the fat test once a fortnight The enumerator has to be present at the time of milking This recording has confirmed the estimated lactation yield of buffaloes in Krishna District at around 2,000 lb (= 900 kg)

The results of the Vijayawada survey make it possible to equate total bovine population and productive bovine population with the available feed and fodder resources, and provides strong support for the policy of removing all non productive animals from a milk procurement area The cows in milk have been assessed at 30,000, this represents 12 5 per cent of the total male and female cattle population, according to Government of India statistics—the total cattle population is therefore 240,000, but milk from cows has been disregarded in planning the project Buffaloes in milk are 120,000, and this represents 25 per cent of the total buffalo population, on the all-India average (Vijayawada may be better than this)—the total buffalo population is therefore 480,000 But only 40 per cent of the milk produced in the district is expected to reach the factory

Contrasting with this, we have the survey of the Bangalore milk procurement area in Mysore State which was done on a so-called statistical sampling basis, by statistical officers, not members of the Animal Husbandry Department A first survey was conducted in 1958 by a team composed of a supervisor, two assistants and six enumerators in part

of the area along the main road to Poona, 20 miles out from Bangalore and covering villages up to 3 miles from that road on either side. All households in all these villages were visited and information was collected. The Chief Statistical Officer reported that the amount of surplus milk in the area appeared to be small, the rainfall is only 25 inches (= 635 mm.) per annum, there are no good tanks or other sources of irrigation, and no buffaloes. Attention was therefore transferred to the region south of Bangalore where new surveys were conducted in 1961 in a group of villages known to specialize in the breeding and maintenance of crossbred cows. The results on which plans and estimates for the milk factory were based did not include house-to-house discussions by animal husbandry specialists with individual farmers, nor any weighing of milk at milking time, nor any subsequent checking of the data initially recorded. Village leaders in selected villages told the survey team how many productive animals there were in their villages, the total milk production, and the proportion of that production which was sold out of the village and which therefore might be available for the milk factory. No checks were made on the access routes to the city to count milk cans on cycles, tongas, buses and trains. Reliable data were not obtained on the cattle population of the area, although it is well known that any future dairy cattle population would have to compete at least with the breeding of Hallikar draught animals, of which the females are of no value for milk production.

In Kerala, statistical officers seconded to the Dairy Development Department have carried out surveys around Trivandrum, Kottayam, Ernakulam, Palghat and Calicut.[89–93] Generally about eight enumerators worked for about five months around each centre, visiting households that keep milch animals up to a radius of about 45 km. from the proposed factory. Around Trivandrum, three zones were recognized, within a radius of 15 km., 15 to 30 km., and 30 to 45 km. from the District Headquarters. The object of these inquiries was to study:

(*a*) marketable surplus of milk within the specified radius, and urban requirements;
(*b*) distribution of households according to the number of cows and buffaloes kept;
(*c*) distribution of animals according to age, production, age at first calving, length of lactations and dry periods;
(*d*) kind, quality and cost of feeds;
(*e*) feeding and breeding resources;
(*f*) marketing channels for milk, and price trends;

(g) human population engaged in milk production, and
(h) location of extension centres for development of rural milk production

These are three examples within the one country of contrasting ways of estimating the factors related to production in a milk procurement area, differing with regard to objective, to the type of staff conducting the survey, the duration and intensity of survey, and the agrarian structure in which the work has been carried out (village communities in Andhra Pradesh and Mysore, every farmer living on his own plot of land in Kerala) The authorities planning such surveys must adapt them to their own conditions, to the availability of reliable statistics, the technological level of the surveying staff and the farmers, and the other factors which must be considered if the results obtained are to have any meaning

Collection of Data

With these reservations in mind, the data which it is desirable to collect include, with reference to the milk procurement area under study

- Basic agroclimatic data
- Total livestock population
- Total bovine population
- Numbers, type and weight of productive bovine population
- Percentage of total productive population in milk at any one time
- Average milk yield per animal on a monthly basis and per lactation
- Length of life and number of lactations (hence total milk yield and lifetime productivity)
- Average long-term yield of best animals to indicate possibilities for selection
- Average age at first calf
- Average interval between calvings
- Possibilities for removal of competitive animals, including dry and young stock, from procurement area
- What do good farmers obtain from average animals by good feeding and management?
- Possibility of including milk recording to facilitate effective culling of low producing animals
- Area under different land use classes within the procurement area (forest, natural grassland, dryland cultivated, and irrigated land)

Botanical composition, possible carrying capacity and length of grazing season of natural grassland.

Size of cultivated holdings, and breakdown into percentage dry and irrigated, type of rotation, crop yields, acreage under cultivated fodders, availability of crop residues, numbers of livestock of all types per holding.

Particulars of plans for development of further irrigation facilities and acreage to be commanded.

Fodder crops likely to be adapted to the region, on the basis of experimental results.

Availability of supplies of seeds and planting material.

Nature and availability of the ingredients of concentrate feed mixes from within economic transportable distance.

Nature and availability of supplies of hay from forest areas or other natural grasslands.

Programmes of Co-ordinated Action

After it has been agreed to establish a milk factory in a particular region, it becomes essential to provide the funds and to train the personnel required to carry out a broad programme of action during the periods before and after collection begins and the stimulus of a reliable market and frequent payment comes into operation.

The following points in a programme of action were prepared for India, but may be found to be applicable elsewhere, or at least to provide a basis for work adapted to specific sites and conditions.

(1) Decision on short and long-term animal breeding policies for the provision of productive dairy animals.

(2) All dairy project areas to be taken for concentrated efforts by Animal Husbandry Departments.

(3) Loans for purchase of better animals.

(4) Removal from within the procurement area of all unproductive bovines, dry animals, sheep, goats, etc., that are likely to compete for the limited fodder resources.

(5) Selection and breeding of improved fodder plants, particularly short-duration legumes.

(6) Elimination of the practice of cultivating unpalatable green manure legumes in milk procurement areas in favour of fodder legumes fed through the animal and returned as dung and urine to the land.

(7) Establishment of special seed farms, with necessary seed-cleaning equipment, so that each major procurement area may be self-sufficient
(8) Provision of clean seed and planting material free or at concession rates in the initial phases
(9) Subsidies for fertilizers, particularly phosphate for legumes
(10) Provision of pump sets and loans for sinking wells
(11) Irrigation water from new dams to be provided on condition that a specified proportion of the land is under fodder crops, or water to be given at concession rates for fodder cultivation
(12) Provision at concession rates of small feed-mixing units, hammer mills, chaff cutters and similar equipment to Milk Unions or Dairy Co-operatives
(13) Operational research and development in fodder production.
(14) Demonstrations to show improved agronomic methods, better varieties, fertilizer practices, methods of harvesting
(15) Comparisons of economic returns per acre from milk at current prices produced from fodder crops fed through good animals with those from food and cash crops, taking into consideration also the effect of fodder cultivation and the full return of dung and urine to the land upon the yield of the food and cash crops
(16) Demonstration that the introduction of a certain percentage of fodder crop acreage into a cropping system, combined with full return of dung and urine to the land, will not reduce and should even increase the total production of food and cash crops from their reduced acreage within the farm or region
(17) Instruction on animal feeding, balanced rations, design of fodder calendars, maximum use of green feed and minimum use of concentrates

Promotion of Dairy Farming

Governments planning to develop a dairy industry must accept the fact that the farmers who are to take up dairy farming for the first time require some financial support and incentive during the early stages Credit in the form of loans or subsidies is required, and may be offered for a number of purposes, depending upon circumstances It should be noted that not all these relate to dairy farming alone

(1) Land clearance, soil improvement and establishment of pastures (Japan, Australia)

(2) Purchase of better livestock, repayable in one to three years (India).
(3) Pasture roads, cableways, etc. (Japan).
(4) Ploughing up and reseeding of old grassland (Great Britain).
(5) Seeds free or at concession rates (India, Japan).
(6) Lime and fertilizers at concession rates (Great Britain, Japan).
(7) Development of irrigation facilities (India, Japan).
(8) Planting of fodder grasses and legumes (subsidy on acreage basis) (Puerto Rico, South Africa, India).
(9) Subsidized price of milk payable to the producer.

Extension, Education and Research

Who is to be responsible for initiating and carrying out the intensive programme of extension among the farmers in a milk procurement area? Should it be the Dairy Project Administrator whose job it is to induce maximum production of milk from the collection areas under his charge in the shortest possible time? Should it be the animal husbandry workers in the area who have the veterinary hospitals, dispensaries and artificial insemination centres? Should it be the fodder agronomists whose job it is to demonstrate to cultivators the economic merits of growing cultivated fodder crops in rotation with the standard food and cash crops, and to follow up these demonstrations by the supply of seeds and planting material at concession rates? Should it be the animal nutrition specialist who advises the livestock owner on how best to use the feed and fodder resources at his disposal, on the basis of a fodder calendar worked out in association with the farmer and the fodder agronomist?

Perhaps the main conclusion that can be drawn from the discussion in the earlier parts of this publication is that milk production is a complex business that is dependent upon many administrative actions and the application of many scientific disciplines. One starts with road layout, rural electrification and the planning of new irrigation schemes, and finishes with the protein content or total digestible nutrients and vitamin content of feeds and fodders. The production of milk up to the stage of the bucket, when what is usually regarded as dairy science comes into action, is a combined operation if ever there was one. It calls for a unified approach, agreement on common objectives and a degree of collaboration between departments and agencies which is all too often lacking in agricultural administration.

How this is to be achieved must be decided by the Government in

question It is not possible to make any blanket recommendations to that effect Successful dairy development depends upon maximum intensification of production—high-quality fodders grown on fertile land that becomes more fertile and productive under a system of integration of crop and animal husbandry, fed to high yielding livestock capable of giving enough milk per unit area of land to make fodder cultivation for the dairy industry competitive in financial return or profit per unit area with the food and cash crops of the region Dairy development is the catalyst which promotes intensification of production and creates conditions for a maximum number of profitable man-hours per unit area

A co ordinated extension effort should be concentrated in the main collecting circle around a milk factory and the satellite circles around chilling centres The radii of these main and satellite circles are governed by the interval that may safely be allowed to elapse between milking and chilling in any particular environment The radius may be quite short in tropical conditions where the safe interval is about two to three hours, and the milk has to be carried by hand or on a bicycle along village roads, possibly with a river crossing in between to delay the process

The concentration of this extension effort will start a chain reaction from these centres of intensive development out to areas beyond the radius of collection of milk Out there, farmers can undertake the maintenance of dry and pregnant animals, the rearing of young stock, and the fattening of male animals for beef Extra feeds and fodders may be grown and sold from within economic transportable distance of the milk collection areas Forest grasslands may be cut for hay, giving employment in more remote areas Farms for the production of seed may be set up Thus a far greater area will benefit from the concentrated extension effort that is made in these oases of really intensive production in the milk procurement areas, and farmers on the fringes will become trained and experienced in dairy farming, ready for the day when they also will come within the orbit of milk collection

It is probably in the matter of farm planning that the extension worker can be of the greatest help to the cultivator who wishes to introduce dairy farming into an exploitive type of enterprise based on the cultivation of fertility removing crops The stimulus created by the existence of a regular and remunerative market for milk can operate to the full only if the farmer can be given advice upon improved methods of animal husbandry, on the incorporation of fodder cultivation into his farming system and crop rotation, and on the use of the available feeds

and fodders in his feeding programme, with maximum emphasis for the sake of economy on home-grown fodders fed in the green or conserved state.

With the increasing realization of the great significance of the production phases in any programme of dairy development, large funds are now being made available for extension work. The next problem to be faced is the serious lack of personnel trained to carry out the work. Education and training now become increasingly important at all levels. As the demand increases, the general training for dairy diplomas, providing a rather superficial coverage of all aspects of dairy technology and dairy husbandry, does not quite provide the type of extension workers that are required. There is a promising tendency to separate the two rather distinct parts into distinct training courses. The dairy husbandry extension worker can therefore devote more time to animal husbandry and crop husbandry in their integrated form called dairy farming. Even this degree of concentration may not be found to be sufficient, and the extension programme will have to be supported by officers with more specialized training in the departments of animal husbandry and agriculture. Again, co-ordination of effort at different levels is the outstanding requirement.

Any extension programme needs to be backed up by an adequate research programme, and this is even more applicable to this relatively new subject, at least in tropical and subtropical latitudes. The animal breeders will in some cases have to develop entirely new breeds of animals to provide types that can respond to a high level of feeding and at the same time make the production of that feed an economic proposition. The plant breeder will have to produce many new cultivars of grasses and legumes, and the research agronomist will have to investigate better methods of growing them. The need is urgent, not least because it takes 10 years to produce a new cultivar and to make it available to farmers in sufficient quantity, 25 to 30 years to produce a new type of dairy animal. It is necessary to define short-term and long-term objectives, using the plant cultivars that are available now and improving the existing livestock as far as may be possible by selection. In this way, reasonable production may be obtained, and the farmers will have become proficient in dairy farming, ready to make full use of the improved plant and animal material when it becomes available.

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Chapter 7

AGE GELATION OF STERILIZED MILKS

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1. INTRODUCTION

The importance of milk in human nutrition has been recognized for a long time Raw milk is a highly perishable product and could be potentially unsafe for consumption without further treatment In addition to being a potential source of pathogenic bacteria, unprocessed raw milk is also susceptible to rapid spoilage by the action of naturally occurring enzymes and contaminating micro-organisms These undesirable attributes can be controlled by the age-old practice of boiling milk shortly after milking and before consumption This practice is still prevalent in many parts of the world where regional handling and distribution of milk are done on a small scale and where refrigeration is not commonly available Pasteurization, which entails milder heat treatment than boiling, ensures destruction of pathogenic bacteria and inactivation of some undesirable enzymes This treatment is more suitable for handling and distribution of larger quantities of milk over wider areas, but refrigeration and a good transportation system are essential if the product is to be stored for any length of time (up to two weeks) before distribution Such facilities are not easily available in countries that are technologically less developed

In industrialized countries, especially those producing milk far in excess of their requirements, there is an increasing trend to process milk in a limited number of centralized dairy plants The distribution of milk to wider and remote areas, particularly where refrigeration is not available, necessitates the prolongation of the shelf life of milk beyond the limits afforded by pasteurization

Several methods have been demonstrated to be effective in preserving

milk for longer periods, for example freezing milk (or concentrates), addition of sucrose to concentrated milk (condensed milk) and sterilization

(i) Milk preserved by freezing retains good flavour but exhibits gradual loss of stability during storage[1,2] The feasible application of freezing as a method of preservation depends upon the availability of refrigeration facilities and economic factors
(ii) Sweetened condensed milk does not require refrigeration and therefore is still a favoured product in many tropical countries[3,4] Its composition restricts its use mainly as an ingredient in other foods, but rapid changes in colour and flavour result from browning reactions because the product is stored at room temperature This product also suffers from another serious defect, namely, gelation during storage[2,5]
(iii) Unlike the above preservation methods, in which microbial growth is suppressed, sterilizing treatments destroy micro-organisms that can proliferate Although microbiological sterility is the primary concern of the sterilizing treatment, the accompanying physical and chemical changes are also of great importance because they affect quality (flavour and nutritional) and shelf life of the product The shelf life is considered in terms of retention of acceptable quality and stability of the product during storage Product stability is a critical aspect of quality during post processing storage and will be discussed in this chapter Specific aspects of the stability of sterilized milk products are emphasized but unsterilized long life products are discussed briefly for the purpose of comparing changes and mechanisms involved in storage stability

2. METHOD OF STERILIZATION

Milk can be sterilized by various techniques such as ionizing radiation, chemical treatment or heating Sterilization by methods other than heating is only of theoretical interest and needs further research to be of any practical use

2.1. Ionizing Radiation

Ionizing radiation destroys bacteria without generating heat but causes several undesirable changes that result in off-flavours and physical

instability of the product during storage [6-9] Radiation is less effective than heat treatment in inactivating enzymes[10] and additional treatment is required to inactivate enzymes Effects of radiation on the properties of milk are not yet fully understood A better understanding of the effects of radiation on the physicochemical changes in milk is necessary before its practical application materializes

2 2. Chemical Treatment

Hydrogen peroxide and antibiotics have been explored as sterilizing agents By themselves these agents are ineffective in sterilizing milk but can reduce the requirements of heat treatment in achieving commercial sterility [6]

2.3. Sterilization by Heat

Effective sterilization of fluid milk products can be achieved by suitable combinations of time and temperature of heating The main considerations in the selection of heating conditions are optimal destruction of micro-organisms, particularly resistant spores, inactivation of deleterious enzymes and retention of desirable attributes of quality in terms of colour, flavour, stability during storage and nutrition Spore destruction bears an exponential relationship to temperature of heating, sterilization efficiency (SE) is expressed by the formula [11 12]

$$SE = \log \frac{\text{Number of spores before sterilization}}{\text{Number of spores after sterilization}}$$

One needs only to consider 'commercial sterility' in which the proportion of *micro-organisms either surviving the sterilization treatment or entering as* post-sterilization contaminants is so negligibly small that it poses no public health hazard Complete sterilization is theoretically possible at higher temperatures but the adverse flavour changes in the product outweigh the beneficial sporicidal efficiency and make such treatments impractical

In practice, heat sterilization of fluid milk falls mainly into two categories

(i) Retort sterilization, in which the product in sealed containers is heated to ~110–120°C for 5–20 min Commercial production and marketing of evaporated milk processed by this method is a long-established practice all over the world [6 10 13 14]

(ii) Continuous flow sterilization is achieved in heat exchangers followed by cooling and aseptic packaging Sterilization temperatures range from 130 to 150°C with a holding period of at least 1 s,

and is generally referred to as 'ultra-high temperature' (UHT) or 'high-temperature short time' (HTST) sterilization In earlier work in the USA, temperatures close to or slightly below 130°C were used to produce HTST sterilized evaporated milk[12 15] but the trend in the USA and Canada is to accept and adopt the European view of UHT treatment using temperatures ranging from 135 to 150°C UHT sterilization of milk is achieved either by direct contact with steam or by indirect heating in heat exchangers Most of the developmental work on UHT sterilized milk was carried out in Europe, whereas most of the work on HTST sterilization of concentrated milk was done in the USA

The essential steps in UHT processing of milk can be described broadly as follows Raw milk is first preheated to 70–80°C for a short period, then sterilized at 130–150°C for 1–5 s, subsequently cooled, homogenized and aseptically packaged

UHT or HTST sterilized concentrated milks are prepared by first forewarming the milk in a vat (90–100°C for up to 10 min) or by UHT methods (130–150°C for 1–5 s), then sterilized by direct or indirect methods (130–150°C for 1–5 s), cooled, homogenized and packaged aseptically Homogenization may precede sterilization The details of UHT processing conditions, types of equipment used in preheating and sterilization, cooling, homogenization and aseptic packaging are adequately described elsewhere[6 12 14 16–20] and are beyond the scope of this chapter The production and marketing of UHT sterilized milk or partially skimmed milk products is now practised in Europe, USA and Canada on an increasing scale [14 18] The commercial production of concentrated milk sterilized by the UHT or HTST methods is still not widespread [6 15]

Both the retort and UHT methods of sterilization are applicable to unconcentrated, as well as concentrated, milk and skim milk Technological, manufacturing, marketing, economical and nutritional aspects of these products have been extensively reviewed [6 10 20]

3 CHARACTERISTICS OF RETORT AND UHT STERILIZED MILK

Fluid milk products sterilized by the retort and UHT methods vary considerably in their initial quality and storage behaviour

Retort sterilized milk or concentrated milk, generally, suffers from

browning discoloration, cooked or caramelized flavour and loss of some nutrients [14] The product is not suitable as beverage milk but may be used as coffee milk or as an ingredient in food formulations [6 13] Provided that they are processed properly, retort sterilized products remain stable for long periods of storage without refrigeration, only slight thinning has been observed [5 21]

In contrast to retort sterilized products, UHT sterilized products prepared by heating in the range 135–150 °C for a few seconds have the advantage of achieving equal or better sporicidal effect without adversely affecting the colour, flavour or nutritional qualities This is possible because at higher temperatures the rate of spore destruction is considerably faster than the rate of most chemical changes [6 12 17 18] For example, the ratio of the bactericidal action to the browning reaction increases exponentially above 135 °C and varies from 1000 to 5000 in the range of 135–150 °C [6 17] However, with UHT sterilized products, loss of stability, in terms of sedimentation and gelation, during storage is a serious problem Undesirable flavour changes during storage are no less important, but these can be modified by selecting proper processing conditions In UHT processed milk, gelation is the most important single problem because it signifies the final limit of shelf life [6 12] The problem of gelation has been the

TABLE 1
EFFECT OF PROCESSING AND STORAGE CONDITIONS UPON SHELF LIFE (GELATION FREE)

Process	*Temp or energy input*	*Time*	*Shelf life (incidence of gelation)*	
			At 4°C	*At 20°C*
Milk				
Pasteurization	62 °C	30 min	5–15 days	< 1 day
	72 °C	16 s		
Sterilization				
Direct	130–150 °C	1–5 s	4–12 months	3–6 months
Indirect			> 12 months	9–12 months
Autoclaved	117–120 °C	10–20 min	> 12 months	> 12 months
Ionizing radiation	1 8 × 10^{-6} rad	—	> 2 months	< 1 month
Concentrated milk (26% TS)				
Sterilization				
HTST or UHT	130–150 °C	1–60 s	> 6 months	2–6 months
Autoclave	117–120 °C	10–20 min	> 12 months	> 12 months
Ionizing radiation	1 8 × 10^{-6} rad	—	2–5 days	10–15 days

major hindrance to the widespread commercial exploitation of the UHT or HTST methods of sterilizing concentrated milk [6,19]

Milks sterilized by different methods vary considerably in stability during storage Approximate shelf life, as indicated by the gelation-free periods during storage, is shown in Table 1 for some heated and sterilized milk products Although not produced commercially, radiation sterilized samples are also included because, similarly to the UHT treated samples, they may also gel during storage Under normal conditions, gelation is not a problem with retort sterilized samples, but under some conditions retort sterilized, evaporated milk does undergo gelation during storage [22,23] This aspect will be discussed separately

4. STORAGE STABILITY: GELATION

Loss of stability in sterilized milk during storage is manifested by the separation of fat, sedimentation of protein and gelation [6,15,19,24]

Fat separation in sterilized milk (or concentrated milk) is not a major problem since it can be controlled by proper heat treatment, homogenization and control of initial viscosity [19,24,25] Likewise sedimentation, which results in separation and settling of solids to the bottom of the container, is also easily controlled by adjusting processing conditions [15,19,24,26] Homogenization following sterilization, for example, minimizes the sedimentation problem [24,27] Except in extreme instances, where the solids sediment and leave a clear liquid at the top, sedimentation is not as serious a problem as gelation Unlike sedimentation, which indicates settling or precipitation of colloidal particles, gelation is characterized by loss of fluidity of the product as a result of changes during storage Gelation has been described by terms such as coagulation,[28,29] sweet curd formation,[30] thixotropic gel formation,[25] age thickening,[19,24,31,32] partial gelation[24,28] or lumpiness [33]

Gelation is strictly a storage defect and should not be confused with thickening during sterilization nor with coagulation observed during incubation of certain evaporated milks at 55°C for 8–10 days During storage, UHT sterilized milk (or concentrated milk) undergoes changes in viscosity, in the initial stages, there is thinning of the product, followed by a fairly long period during which very little change in viscosity is observed, terminated by a period during which there is a sudden rise in viscosity culminating in gel formation within a short period (1–3 weeks) Samples that are viscous or are at an early stage of gelation can be easily dispersed to

a thin consistency by agitation However, these samples revert to the viscous state within 24–48 h [15 34] When gelation occurs the product exhibits a custard-like consistency and the process is irreversible at this stage The gels are characterized, in most instances, by absence of syneresis[33] but on further storage syneresis does occur in gelled products [34]

Changes in viscosity and gelation during storage were first recognized by Deysher *et al* [35] and by Bell *et al* [36] during their early work on sterile concentrated milk prepared by HTST processes These workers observed that evaporated milk (26% TS) sterilized by the HTST method (135°C for 30 s) gelled within 6–16 weeks of storage at 30°C Subsequently, these findings were confirmed by numerous workers who observed similar viscosity changes during storage in UHT sterilized milk,[28 37 38] concentrated milk[15 33 39–41] and concentrated skim milk [34]

A typical viscosity change during storage of HTST sterilized evaporated milk is illustrated in Fig 1 The sample sterilized at 117°C (243°F) for 13 min shows only the initial thinning but no increase in viscosity for a long

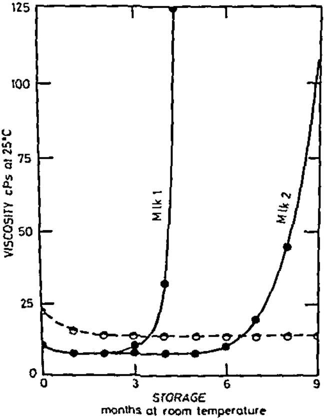

FIG 1 Viscosity of sterilized evaporated milk (26% TS) ● Milk 1 and Milk 2 samples sterilized by HTST at 130°C for 1 min ⊖ milk sample sterilized at 117° for 13 min Data from Tarrasuk and Tamasma [33]

period during storage Many studies carried out on gelation, particularly in unconcentrated milks, do not report viscosity data, in the absence of which it is difficult to compare results from different laboratories since it is not certain whether the gelation processes described by various authors are similar Description of storage destabilization by such terms as 'wheying of' or 'clearance'[29 42] is indicative of sedimentation rather than gelation

5. FACTORS AFFECTING GELATION

The problem of gelation in UHT sterilized milk is considered to be less critical than with UHT sterilized concentrated milk In fact, the gelation problem in sterilized milk was recognized much later than in sterilized concentrated milk For this reason, storage gelation of UHT sterilized concentrated milk has been studied more extensively than sterilized milk,[12 13] although in recent years an increased concern regarding the gelation of sterilized milk is evident in the literature [18 32] The time at which gelation occurs during storage of UHT sterilized concentrated and unconcentrated milks is influenced by many variables (Table 2), some of which have been studied extensively Although most of the factors indicated are applicable to both unconcentrated and concentrated sterilized products, the extent and specific application vary somewhat

5 1. Heat Treatment

The major factor contributing to storage gelation in unconcentrated milk is the severity of the heat treatment to which the milk is subjected It is now well recognized that retort sterilized milk (115–120 °C for 15–20 min) remains resistant to gelation for long periods of storage, whereas UHT sterilized milk gels during storage The period of gelation was found to depend upon the time and temperature of the heat treatment either before or during sterilization Samuelsson and Holm[28] observed that sterilization by heating at 152 °C gave a milk with a longer gelation-free shelf life than sterilization by heating at 142 °C, an increase in the time of heating from 6 s to 12 s increased resistance to gelation Zadow and Chituta[43] observed a moderate delay of the gelation time by pre heating at 72 °C for 30 s or at 80 °C for 30 min and by increasing the sterilization temperature and the holding time as illustrated in Table 3 Similar increased protection against gelation by increasing the severity of sterilization was observed by others as referenced in Table 2

Gelation is also influenced by the UHT sterilizing method [38 44 45]

TABLE 2
FACTORS AFFECTING GELATION OF UHT STERILIZED MILK OR CONCENTRATED MILK

	References
Processing conditions	
Forewarming	15, 27, 33, 35, 36, 40, 50, 51, 61, 141, 142
Time and temperature of sterilization	12, 13, 15, 19, 28, 43, 45, 49, 90, 141
Direct or indirect UHT treatment	12, 38, 44, 77, 80
Homogenization	15, 27, 41, 139
Sequence of operations	24, 27
Composition of milk	
Total solids	5, 15, 27, 33, 52
Mineral balance	15, 37, 42, 43, 99
Protein composition	15, 57
Seasonal variation	13, 15, 43
Quality of milk	13, 43, 56
Additives	
Mono- and di-sodium phosphate	2, 19, 25, 27, 29, 34, 39, 139
Citrate	28
Carbonate	19, 28
Polyphosphate	2, 19, 29, 34, 63, 93
Polyhydric alcohols	2
Minerals (Ca, Mn, etc)	2, 15, 28, 35, 39
Oxidizing or reducing agents	
H_2O_2, antioxidants	22, 68, 140
Phosphatides	2
Sulphydryl reagents	67, 140
Temperature of storage	2, 15, 27, 37, 38, 40, 43, 45, 48, 70–72, 96, 121, 125

Sterilization by direct heating methods has been shown to offer less protection against gelation during storage than sterilization by indirect methods This is believed to result from the inherent difficulty in controlling the severity of heat treatment in the indirect method The wide variation in the length of the gelation time, ranging from less than 3 months to over 12 months, as observed by many investigators,[24 29 34 43 46-49] could be attributed, at least in part, to the different methods of sterilization

In concentrated milk, heat treatment, generally, affects gelation in a manner similar to that in milk However, forewarming, a beneficial step in improving stability of concentrates during sterilization in containers by

TABLE 3

EFFECT OF PREHEATING, STERILIZATION AND STORAGE TEMPERATURES ON GELATION TIME OF UHT MILK[a]

Pretreatment	*UHT processing conditions*		*Storage temperature (°C)*	*Time of gelation (days)*
	Temp (°C)	*Time (s)*		
Nil	140	3	30	96–99
72°C/30 s	140	3	30	110–113
80°C/30 min	140	3	30	117–120
	135	3	30	96–99
	140	2	30	96–99
	140	3	30	96–99
	140	5	30	110–113
	140	3	2	>208
	140	3	15	130–133
	140	3	20	130–133
	140	3	25	96–99
	140	3	30	96–99
	140	3	35	110–113
	140	3	40	>208

[a] Data from Zadow and Chituta [43]

retort methods, plays a very important role in the gelation phenomenon of HTST sterilized, concentrated milk HTST methods do not have the stability problem *during* sterilization because of the short holding periods at high temperatures Forewarming treatments at a higher temperature and for longer periods delay gelation but sedimentation defects and flavour deterioration resulting from excessive heat treatment limit its use [12 18 25] A typical beneficial effect of forewarming is illustrated in Table 4

Sterilization (HTST) of concentrated milk at higher temperature and longer holding times also retards gelation However, at equivalent sterilizing effectiveness, higher sterilization temperatures with shorter exposure times result in reduced resistance to gelation [15 25 49] Heat treatments in excess of those required for sterilization are needed to achieve greater stability against gelation For example, Bell *et al* [36] observed that a 2 1 milk concentrate (26%TS), processed at 135°C for 30 s and subsequently heated at 115°C for 2, 6, 12 and 18 min, started to thicken after 32, 36, 41 and 51 weeks of storage respectively

TABLE 4
EFFECT OF FOREWARMING TREATMENT OF MILK UPON TIME REQUIRED TO THICKEN CONCENTRATED MILK STERILIZED AT 135°C FOR 30s[a]

Total solids, TS (%)	*Forewarming*		*Time required to thicken at 30°C storage* (*weeks*)
	Temperature (°C)	*Time* (*min*)	
26	65	10	16
26	120	4	24
32 5	65	10	10
32 5	120	4	13

[a] Data derived from Bell *et al* [36]

5.2. Homogenization and Sequence of Operation

Homogenization, used to control fat separation and sedimentation in unconcentrated milks processed by UHT or HTST methods, also influences their gelation behaviour The placement of homogenization, as well as other processing steps, in the sequence of operations is an important factor in the storage stability of UHT treated products There are fewer processing steps in UHT treatment of unconcentrated than of concentrated milk Consequently, the sequence of carrying out the different steps is of considerable influence on storage stability of concentrated milk Placing the homogenization step before concentration and sterilization gives a product with reduced stability against gelation [27] Concentration before sterilization gives a product more stable to gelation [27] Typical effects of changing the sequence of the processing steps are illustrated (by control samples) in Table 5 Factors which prevent gelation often promote sedimentation during storage, an inverse relationship exists between susceptibility to sedimentation and susceptibility to gelation [12 18 51 52]

Another processing step which significantly influences the gelation behaviour, is to hold the sterile concentrate at 94°C to allow development of a critical viscosity The incipient coagulum is then destroyed by homogenization under aseptic conditions [52 53] This treatment has been shown to retard gelation during storage However, the problem is one of determining the optimum viscosity at which homogenization is carried out Homogenization of excessively thick product results in graininess and sedimentation whereas homogenization below the optimum level of thickening results in gelation

TABLE 5

EFFECT OF SEQUENCE OF OPERATION AND ADDITIVES ON SHELF LIFE OF HTST STERILIZED MILK AT DIFFERENT TEMPERATURES OF STORAGE[a]

Storage temperature (°F)	*Additive*[b]	*Storage life (days)*	
		FCASH[c]	*FHASC*[d]
70 (21 °C)	Control	45	7
70	Monophosphate	16	3
70	Polyphosphate	441	240
86 (30 °C)	Control	30	5
86	Monophosphate	13	3
86	Polyphosphate	220	76
99 (37 2 °C)	Control	26	6
99	Monophosphate	10	3
99	Polyphosphate	84	36

[a] Data taken from Leviton *et al* [27] All samples were 36 % total solids and were forewarmed and sterilized at 138 °C for 15 s
[b] In the proportion 0 4 lb additive/100 lb milk solids
[c] Forewarming Concentration–Additive–Sterilization–Homogenization
[d] Forewarming–Homogenization–Additive–Sterilization–Concentration

TABLE 6

EFFECT OF TOTAL SOLIDS AND STERILIZATION CONDITIONS UPON GELATION TIME DURING STORAGE AT ROOM TEMPERATURE

Total solids (%)	*Sterilizing time at 132 °C (s)*	*Time to gel (weeks)*
26	35	33
26	70	42
36	35	12
36	70	16–20

Data derived from Figs 5 and 6 from Ellertson and Pearce [15]

5.3. Total Solids

Gelation of concentrated milk, sterilized by HTST or UHT methods, is hastened by increasing total solids [5 15 27 33 36 52] Increased severity of heat treatment has less influence on retarding gelation of concentrates containing higher total solids The data in Table 6 illustrate the effect of total solids and severity of sterilizing treatment upon the time of gelation It is also interesting to note that the heat treatment given to over-concentrated milk (32–45 % TS), followed by dilution to 26 % TS, imparts to the diluted milk a greater stability against gelation [54]

5.4. Composition of Milk

Since sterilized skim milk concentrates are highly susceptible to gelation, hastening of gelation by increasing the total solids content in UHT sterilized milk is generally assumed to be due to the solids-not-fat portion, whereas fat is not directly involved in gelation [13 33]

Different milk proteins added to milk affect the gelation behaviour of UHT sterilized products Addition of dialysed acid whey to milk to increase whey protein contents by 10 % and subsequently processing the milk into evaporated milk (26 % TS) sterilized by the HTST method, markedly hasten the onset of gelation Doubling the sterilizing time is relatively ineffective in overcoming the increase rate of gelation [15] Addition of α_s-, β- and κ-caseins to milk influence the characteristics of the casein micelles but do not affect the gelation period of UHT sterilized concentrated milk [55]

5.5. Quality of Milk

Some factors that influence the composition of milk may indirectly affect the gelation behaviour of sterilized milk For example, seasonal variation, known to affect composition, influences gelation [13] Summer milk gives more stable products than winter milk[43] and mastitic milk subjected to UHT treatment is more susceptible to gelation than normal milk [56] Evaporated milk from Jersey cows with a high protein/water ratio is more susceptible to gelation than evaporated milk from other breeds [57] Early-lactation milk is more susceptible to storage gelation of UHT products [13 43]

Bacteriological quality of raw milk is also important in gelation, sterilized milk from poor quality milk is very susceptible to gelation during storage [29 43 56 58 59] The type of micro-organisms or spores present in poor milk is important,[29 43] organisms that produce heat-stable enzymes, e g proteinases, cause most serious gelation problems

The widespread practice of holding cooled raw milk in bulk tanks for

extended periods increases the possibility of growth of psychrotrophs that produce heat-stable proteinases, which could affect storage stability Thermization treatment, which consists of subjecting raw milk to a quick heat shock (63–65°C for 12–15 s) before storage in bulk tanks, has been recommended to minimize the growth of psychrotrophs [14] This treatment is less severe than pasteurization and is effective against psychrotrophs but not against the action of proteolytic enzymes

5 6. Enzyme Treatment

Modification of milk by pretreatment with rennet or neuraminidase before sterilization has been reported to increase stability against gelation [13 50]

Addition of heat-resistant proteinases or inoculation with psychrotrophs that produce heat resistant proteinases hastens gelation, this aspect will be discussed later However, West *et al* [60] have suggested a low temperature treatment to inactivate some types of heat-resistant proteinases, about 90% of the proteolytic activity is destroyed when UHT treated milk is cooled to about 55°C and held for 60 min, apparently, by mechanisms different from the inactivation by high-heat treatment

5.7. Additives

Extensive studies have been made to develop additives which would be effective in controlling gelation of sterilized milk (or concentrate) during storage Additions of sodium phosphate and citrate hasten while polyphosphates delay the gelation process in both UHT sterilized milk[28 29] and concentrated milk [2 27 34 61–64] These additives are known to improve heat stability of concentrated milk during retort sterilization [5] Polyphosphates, on the other hand, significantly delay gelation, the extent of protection against gelation increases with chain length and concentration of the polyphosphate, polyphosphate with an average of 4 8 phosphorus atoms per chain was effective against gelation [2 27 61] Typical effects of orthophosphate that hasten gelation and of polyphosphate that delay gelation are evident from data shown in Table 5 The phosphates also show similar effects on the stability of concentrates preserved by freezing or by high concentrations of sugar [1 2 4] Polyphosphates also delay rennet coagulation [65] Cyclic condensed phosphates are more effective against gelation than linear polyphosphate because the former are less susceptible to hydrolysis than the latter [2 61 66] A mixture of monophosphate and polyphosphate augments gelation [2 13 61]

Addition of manganous sulphate is also effective in delaying gelation [61]

Interestingly, gelation of milk concentrates sterilized by ionizing radiation is also inhibited by polyphosphate and manganese salts,[7,8] suggesting a common mechanism of gelation of both heat and radiation sterilized concentrates

Other additives that delayed gelation of sterile concentrates are polyhydric compounds like lactose, sucrose, dextrose and sorbitol [61] Added phosphatides also increase storage life [61] Sulphydryl blocking agents, such as PCMB, *N*-ethylmaleimide and iodoacetamide, retard gelation while disulphide reducing agents, such as mercaptoethanol, thioglycolate and glutathione, promote gelation of sterile concentrates [67] Addition of hydrogen peroxide to UHT sterilized skim milk concentrate hastens gelation [68]

Addition of sodium hydroxide[69] or sodium carbonate[19] to adjust the pH of a 3 1 sterile concentrate to near neutrality delays gelation but adjusting the pH of unconcentrated milk before UHT sterilization has no effect on gelation [43]

5.8. Temperature of Storage

Time of gelation of UHT sterilized milk is markedly influenced by the temperature of storage However, there is not unanimous agreement between different investigators regarding the effect of storage temperature upon gelation Samel *et al* [70] observed the gelation time (13 months) to be independent of storage temperatures between 4 and 30 °C, and at 37 °C there was no gelation for two years Improved resistance to gelation during storage at 35 °C and above was also observed by others [43,46,48,71,72] Zadow and Chituta[43] observed minimum gelation free storage life at 25–35 °C but the storage life was extended considerably at 2 °C or at 40 °C as shown in Table 3 Andrews *et al* [71] noted that samples of UHT sterilized milk stored at 4 °C gelled in 19 months, but samples stored at 30–35 °C had not gelled in 28 months Hostettler *et al* [72] observed that UHT sterilized milk, stored in glass containers, gelled in ten months at room temperature but remained liquid at 35 °C The sample in glass at 35 °C turned brown but remained white when stored in tin containers at 35 °C and gelled at about the same time as the sample stored at room temperature

There is better agreement regarding the effect of storage temperature upon gelation time of concentrated milk sterilized by UHT or HTST methods Generally, the higher the temperaure of storage, the earlier the gelation of samples [15,27] The extent of temperature dependence of gelation time varies The gelation rate of HTST sterilized evaporated milk (25 % TS) was about three to four times higher at 38 °C (100 °F) than at 21 °C (70 °F)

storage[15] The data of Leviton *et al*,[27] shown in Table 5, indicate in control samples a lesser effect of storage temperature upon gelation time for samples containing higher total solids (36%)

The effect of storage of HTST concentrates at 35°C and above is different from that of unconcentrated milk sterilized by UHT treatment In contrast to the sterilized unconcentrated milk, the sterile concentrates were less stable at 38°C than at lower temperatures (compare data in Table 3 and in Table 5)

6. PHYSICAL AND CHEMICAL CHANGES RESULTING FROM UHT STERILIZATION TREATMENT AND STORAGE

Although various processing and storage conditions are known to affect the gelation of UHT sterilized milk, as shown in the preceding section, the precise mechanism of gelation is still not fully understood It is now generally accepted that storage gelation is not caused by microbial activity of either surviving heat-resistant spores or post-sterilization contaminants[24 30] In an effort to gain a better understanding of the gelation phenomenon, numerous investigations have been made on the physical and chemical changes occurring immediately following sterilization and during storage

6.1. Changes in Milk Immediately After Sterilization

Several changes may result from heat treatment of milk during sterilization The extent of these changes is generally less with UHT sterilization treatment than with retort sterilization The changes that could be of possible significance for gelation are, particularly, those that affect proteins, enzymes and the mineral balance

6 1 1 Protein

As a result of heat treatment, i e both the forewarming treatment and sterilization, an association takes place between whey proteins (β-lactoglobulin) and casein[73-76] Whey proteins either become denatured or interact with components of casein micelles (κ-casein) and become sedimentable with casein or co-precipitable at the isoelectric point of casein[5 24] The extent of association between whey proteins and casein varies with the severity of heat treatment[12 50 77-80] For example, heating at 146°C for 16 s causes less denaturation than heating at 90°C for 10–30 min[50] UHT sterilization by direct heating methods denatures less

whey protein (60–70%) than indirect heating (70–80%) of milk[12,81] The heat-induced changes in whey proteins cause shifts in nitrogen distribution as measured by the different methods of partitioning proteins in milk[34,82,83] The extent of complex formation between denatured β-lactoglobulin and κ-casein, predominantly through disulphide bridges,[74–76] significantly modifies the properties of casein micelles Heat-altered casein micelles are more resistant to coagulation by heat[21,84] and enzymes,[12,24,70,85–89] and to storage gelation (Table 2) and less sensitive to treatment with oxalate that removes calcium ions[50] A higher proportion of whey protein complexed at the surface of casein micelles offers better protection against gelation[12,45,90]

UHT treatment of milk is also known to cause some rearrangements of casein components in the micellar structure through a simultaneous process of disaggregation and aggregation reactions[31,64,90–95] Thus, in UHT sterilized milk or concentrated milk, while there is an increased amount of casein (submicelles) not sedimentable on high speed centrifugation (> 100 000 *g*), there is also an increase in the size of the casein micelles The non-sedimentable casein particles (submicelles) have diameters of less than 20 nm The increase in the size of sedimentable casein micelles is slight in UHT sterilized milk[92,94] but a two- or three-fold increase is observed in sterilized, concentrated milk[12,63,68,90] The size enlargement results from a coalescence process[63,68,94,96] The importance of increased dimensions of casein micelles for the gelation process is not known

6 1 2 *Mineral Balance*

Changes in the inorganic constituents of milk occur as a result of heat treatment Decreases in ionic calcium and magnesium result from their precipitation as phosphate and citrate salts[42,96–99] Reduction in the level of soluble calcium by UHT treatment may be insufficient to be of any significance to gelation Furthermore, the role of calcium in the gelation is not clear Additives such as phosphates or citrates, that reduce the availability of calcium, promote gelation Moreover, increasing the level of calcium by 6% did not affect gelation,[15] small amounts of calcium delay gelation[13] but larger increases of calcium hasten it[28,39] Another indication that calcium plays an uncertain role in gelation is the protection against gelation by polyphosphates Cyclic polyphosphates complex calcium to a lesser extent than linear polyphosphates, yet the former retard gelation more effectively[2,61] The effectiveness of polyphosphates is believed to result from their ability to complex with casein micelles,[21,100,101] thus preventing their interaction by charge repulsion

6 1 3 Enzyme Activity
Proteinases that are naturally present in milk or that are of bacterial origin are not always completely inactivated by the heat treatment in the UHT process Proteolytic enzymes that survive UHT sterilization have been isolated from UHT treated milk [102,103] On the other hand, no proteinase was detected in HTST concentrated milk[104] or in 10% UHT cream,[105] even though protein breakdown was evident during storage Proteolytic enzymes of psychrotrophic bacteria are heat-resistant Indigenous milk proteinase, which has characteristics similar to those of blood plasmin,[32 106] is less heat-stable [107] The action of these enzymes during storage is of considerable significance to the problem of gelation and will be discussed in greater detail in the following sections

6.2. Changes During Storage
Sterilized milk undergoes several physical and chemical changes during its storage The changes that affect organoleptic and nutritional quality will not be discussed here since they are presumed not to be directly involved in gelation Some of the changes that are implicated in the storage gelation of sterilized milk are listed in Table 7 Though the changes occur qualitatively in both non-concentrated and concentrated milks which had been sterilized by UHT treatment, the extent of these changes differs in quantitative terms

Changes during storage of sterilized milk affect the stability of the colloidal calcium–caseinate–phosphate complex of milk The sensitivity of the complex to coagulation by such agents as ethanol, rennet and calcium are indicative of general stability Data presented in Table 8 show typical behaviour of sterilized milk during storage at 20°C

6 2 1 Stability to Ethanol
Alcohol stability is determined as the minimum percentage of ethanol which when added to an equal volume of milk causes its coagulation Milk coagulating at a lower concentration of ethanol is less stable During storage UHT sterilized milk shows a gradual loss of stability to alcohol (Table 8) This loss of stability appears to correlate with gelation during storage, since retort sterilized (autoclaved) milk, that did not gel during storage, remains unchanged in its stability to ethanol At a lower storage temperature the stability to ethanol decreases more rapidly in UHT sterilized milk than in autoclaved milk [70] A decrease in alcohol stability was also observed during storage of UHT sterilized concentrated milk [34] UHT sterilized concentrates are less stable than diluted UHT sterilized milk Samples containing polyphosphates, that delay gelation, are more stable to ethanol than samples in which the onset of gelation is hastened

TABLE 7

PHYSICAL AND CHEMICAL CHANGES DURING STORAGE OF UHT STERILIZED MILK

Property	*Unconcentrated milk*	*Concentrated milk*
Physical		
Stability to ethanol	↓	↓
Stability to calcium ions	↓	↓
Rennet coagulation time	↑	↑
Aggregation of proteins	↑	↑
Non-sedimentable casein	↑	↑
Ca/N ratio of the sediment	↑	↑
P/N ratio of the sediment	↑	↑
Viscosity (relative)	↑	↑
Chemical		
pH	unchanged	unchanged
Maillard-type reaction (browning)	↑	↑
Sulphydryl groups	↓	↓
Protein breakdown		
Casein nitrogen	↓	↓
Non-casein nitrogen	↑	↑
Non-protein nitrogen	↑	↑
N-Acetylneuraminic acid	unchanged	unchanged
Dephosphorylation (P_i)		

↑, Increase, ↓, decrease

TABLE 8

STABILITY OF PROTEINS IN MILKS STERILIZED BY UHT AND AUTOCLAVING AND STORED AT 20°C[a]

Stability of protein	*Storage (months)*				
	0	*2*	*5*	*9*	*13*
Stability to ethanol (%)					
UHT milk	96	96	83	62	gelled
Autoclaved	>96	>96	>96	>96	>96
Stability to calcium ($ml\ 0\ 1\ M\ CaCl_2$)					
UHT	2 8	1 4	0 8	0 2	gelled
Autoclaved	2 1	1 8	2 0	1 8	2 0
Rennet coagulation time (min)					
UHT	50	50	12	4	gelled
Autoclaved	>120			>120	120
Raw milk	7	—	—	—	—

[a] Data from Samel *et al* [70]

6 2 2 Stability to Calcium

Rennet-treated milk shows a decreased stability to added calcium ions,[21 70 72 99] i e the amount of calcium required to cause precipitation of casein is reduced The decreased stability to calcium has been ascribed to a loss of the protective action of κ-casein due to its proteolytic breakdown A similar loss of stability to calcium has been observed with aged sterile milk[70 72 108] although to a lesser extent than in rennet-treated milk[72 108] Samel *et al*[70] observed a gradual decrease in stability to calcium during the storage of UHT sterilized milk but not in retort sterilized milk (data in Table 8 are for samples stored at 20°C) At a higher storage temperature,[109] the loss of stability to calcium was faster than at lower temperatures, which was attributed to the increased chemical modification at higher temperatures by Maillard-type reactions between ε-NH_2 of protein and reducing groups of lactose or its degradation products[109] The calcium sensitivity of autoclaved milk stored at 4°C decreased but at a slower rate than that of UHT sterilized milk[70] The UHT treated sample gelled in 13 months but autoclaved milk did not Thus, there is no consistent relationship between increased calcium sensitivity and gelation

6 2 3 Rennet Coagulation Time (*RCT*)

Heat treatment of milk increases the RCT to varying extents depending upon the severity of heat treatment The RCT is considerably longer for UHT sterilized milk than for raw milk but markedly lower than for autoclaved milk (Table 8) Casein micelles in skim milk sterilized by indirect UHT treatment, when compared with direct UHT treatment, were more stable during storage as well as to the action of rennet[110] The RCT is affected by the formation of a heat-induced complex between β lactoglobulin and κ-casein which may hinder the availability of the sensitive Phe–Met bond in κ-casein to attack by rennet[5 50 88 111] Also, shifts in ionized and colloidal milk salts may alter the charge and surface properties of casein micelles[21 32 72 98]

Samel *et al*[70] observed that the RCT progressively decreased in UHT sterilized milk during storage after six months of storage, the RCT of UHT milk was the same as for unheated milk The RCT of autoclaved milk was unchanged (Table 8)

The reduction of RCT during storage of UHT sterilized milk is indicative of some subtle reversible and as yet poorly understood changes at the surface of the casein micelles the unchanged RCT of autoclaved milk during storage is indicative of irreversible changes These considerations regarding the rennet coagulation behaviour of stored sterilized milk are

consistent with the hypothesis of Hostettler[24 90] in which storage gelation is linked to incomplete or reversible interaction between whey protein and casein However, it is not certain if the change in RCT and gelation during storage are governed by a common physical condition of the casein micelles

6 2 4 Shifts in Mineral Balance

During storage of UHT sterilized milk many changes are observed in the distribution of mineral components Initially, some of the calcium phosphate, precipitated by the UHT treatment, dissociates[5 84 90] and binding of calcium and phosphate by the casein is readily reversed Prolonged storage, on the other hand, causes precipitation of some forms of calcium phosphate [37 42 97] Since colloidal calcium phosphate is necessary for the stability of casein micelles, changes in the mineral balance affect stability

The manner in which these shifts in mineral balance affect stability is not clear Increased dissociation of casein micelles is caused by removal of calcium[5 91 112] and therefore the increased non-sedimentable casein observed during storage could arise from such a removal However, Aoki *et al* [37 42] observed that Ca/N and P/N ratios of the casein fraction sedimentable by ultracentrifugation ($> 100\,000\,g$) increased during storage of UHT skim milk This increase was of smaller magnitude than in UHT concentrated skim milk These investigators attributed the destabilization of the casein complex during storage to the incorporation of calcium and phosphate into it However, an increase in Ca/N ratio in the ultracentrifugal casein complex was also observed in stored autoclaved milk and this makes the explanation less tenable There is no discernible pattern of mineral distribution that satisfactorily explains the mechanism of gelation during storage

6 2 5 Disaggregation, Aggregation and Microstructure of Casein Micelles

During storage of UHT milk, caseinate particles undergo a number of changes as measured by ultracentrifugal sedimentation, gel permeation chromatography[46 109 113] and light[64 93] and electron[24 38 48 62 63 68 71 90 95] microscopy Firstly, an increase in the amount of non sedimentable casein (at $> 100\,000\,g$) is observed The increase in non sedimentable casein is assumed to result from a partial disaggregation of the casein micelles[31 64] and is seen by electron microscopy as fine particles or subunits of casein [63–68] The dissociation of large casein particles is more rapid at 4 than at 20 or 37 °C The forces that lead to such disaggregation are not, as

yet, well understood but shifts in the mineral balance seem to be involved, as indicated in the preceding section Secondly, increased formation of protein polymers is observed[37 42 46] during storage These polymers result from covalent binding or cross-linking of casein polypeptide chains through carbonyl intermediates resulting from Maillard-type reactions [46 109 113] The polypeptide chains may also be linked through disulphide bonds The extent of polymer formation is dependent upon time and temperature of storage After six months of storage, the proportion of milk proteins existing as covalently bound polymers is 50 % at 37 °C, 40 % at 30 °C, 26 % at 20 °C and 21 % at 4 °C The extent of polymer formation does not appear to be related to gelation time since UHT milk stored at 4 °C gelled sooner than milk stored at 30 or 37 °C, although the milk stored at 4 °C contained the lowest amount of polymers [46]

In addition to the above two changes, which progress independently of viscosity changes, there are changes in the structure of casein micelles that coincided with the observed changes in viscosity or gelation Examination of microstructure by electron microscopy shows that, during storage, the casein micelles associate increasingly during the period in which a rapid increase in viscosity and gelation occurs [48 68] The changes in microstructure observed during storage of UHT treated milk are gradual, those occurring in UHT sterilized concentrated skim milk are illustrated in Fig 2 During the initial period, when there is no change in viscosity, the micelles remain spherical and well separated from each other but the surface appearance changes and the filamentous appendages, attributed to denatured β-lactoglobulin,[114] or 'hairiness'[68] on the micelle surface become less prominent After ten weeks of storage when viscosity starts to rise, the casein micelles show a slight distortion and thread like tails on the micelle surface (Fig 2b) Similar deformation of the micelle surface and tendrils protruding from it were also observed before gelation in UHT milk [38 71] After 13 weeks of storage of concentrated skim milk, when the milk had become viscous, pairs or triplets of casein micelles were observed (Fig 2c) The micelles were attached either by fusion between micelles or by thin, fibre-like material, analogous to the bridging material described by Carroll *et al* [96] At this stage, the micelles still retained their identity and there were several unattached individual micelles present The pairs and triplets of micelles observed in this sample were perhaps equivalent to the increase in micelle size observed by Andrews *et al* [71] and to the increased amount of casein particles sedimented by low-speed centrifugation (3000 *g*) as observed by Aoki and Imamura,[37] in stored UHT milk After 17 weeks of storage, when the sample had gelled, there was an indication of severe

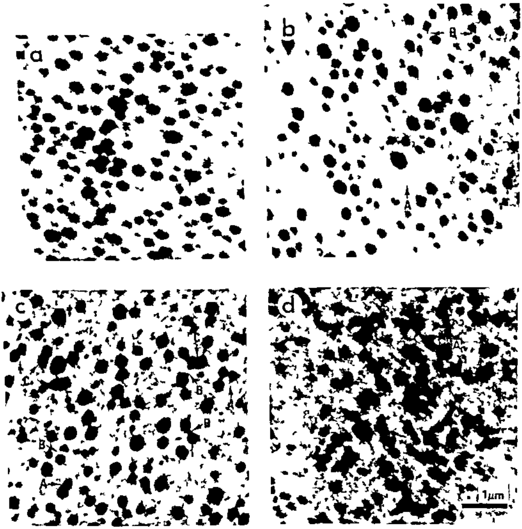

FIG 2 Changes in the microstructure of UHT sterilized concentrated skim milk stored at 28°C (a) Immediately after sterilization, viscosity = 21°M (b) After 10 weeks, viscosity = 26°M, A, non-micellar particles, B, distorted casein micelles with thread like tails (c) After 13 weeks, viscosity = 120°M, A, distorted casein micelles with thread-like tails, B, fibre-like material joining casein micelles, C, clusters of fused casein micelles (d) After 17 weeks, solid gel A, fibre like material joining clusters of casein micelles Data from Harwalkar and Vreeman [68]

distortion and aggregation of casein micelles into chains which were connected through fibre-like material to form a continuous network (Fig 2d) Network formation by linkages between casein micelles has been observed by others in gelled concentrated[24 62-64 90 96] and unconcentrated milks [38 48 71] Gelation results from gradual changes in the casein micelles rather than from an abrupt coalescence of micelles shortly before gelation [62 63] The abundance of non-micellar particles increases with storage but their involvement in gelation is uncertain

Samples of UHT sterilized concentrated skim milk, containing orthophosphate, also showed changes in microstructure at various stages of gelation [68] These samples became viscous or gelled sooner than the samples without orthophosphate and changes in their microstructure also were seen earlier Samples containing hexametaphosphate showed little change in microstructure during storage and the micelles remained mostly unchanged and well separated Compared to a sample examined immediately after sterilization, samples stored for 17 weeks contained micelles that had a smoother surface and were of a smaller size (Fig 3A vs Fig 3B) Samples of retort sterilized milk and samples of UHT milk stored at 45°C, neither of which gelled during storage, also contained micelles that remained well separated from each other [48]

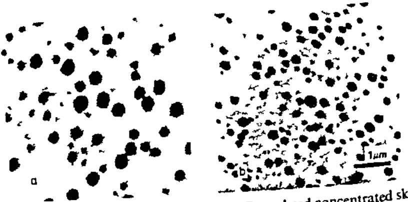

FIG 3 Changes in the microstructure of UHT sterilized concentrated skim milk containing polyphosphate (1 5 g per kg milk) A, Immediately after sterilization, viscosity 17°M B, after 17 weeks viscosity 15°M Data from Harwalkar and Vreeman [68]

The characteristics of the microstructure of gels from stored UHT milk or concentrated skim milk are quite different from the microstructure of gels produced by the action of chymosin The latter gels show only clumping of casein micelles and do not show the surface deformation and thread like bridging between micelles that is typical of storage gelled products [68 71 115]

6 2 6 *Protein Breakdown*

Destabilization of casein micelles during storage of sterilized milk could result from either dephosphorylation or cleavage of peptide bonds of proteins Dephosphorylation, which is observed in milk given excessive heat treatment,[5 116] has not been demonstrated to occur during storage [34]

Evidence of proteolysis is voluminous, and therefore considerable attention has been directed to find a relationship between proteolysis of sterilized milk and its gelation during storage During their early investigations, Hostettler *et al* [72] observed decomposition of casein in UHT sterilized milk that had gelled during storage and Samuelsson and Holm[28] observed an inverse relationship between the increased level of non-protein nitrogen and time of onset of gelation Both groups of investigators attributed the decomposition of proteins to reactivated proteolytic enzymes Reactivation of phosphatases in heated milk is known [117 118] Subsequently, numerous investigators have observed protein breakdown during storage of both unconcentrated[46 47,70 119 120] and concentrated milk[24 29 64 68 90] sterilized by UHT treatment During storage, a progressive decrease in the amount of casein nitrogen and a corresponding increase in non-casein and non-protein nitrogen was observed in these samples Typical changes during storage of UHT sterilized milk in the fractions partitioned by the scheme of Aschaffenberg and Drewry,[47 82] are illustrated in Table 9 Although others have observed similar changes, there is considerable variation in the extent and rate of proteolytic change The differences are assumed to result from variations in the conditions of processing treatment and the quality of milk UHT treatment by the 'direct' method results in a higher degree of proteolysis during storage than in milk sterilized by the 'indirect' method or by autoclaving [28 38 70 121] The survival of heat-stable

TABLE 9
CHANGES IN NITROGEN DISTRIBUTION IN UHT STERILIZED MILK DURING STORAGE AT ROOM TEMPERATURE[a]

	Nitrogen distribution[b] (%)				
	Before sterilization	*After sterilization*	*Storage (months)*		
			2	4	5
Casein N	80 3	84 4	80 8	75 5	72 1
Non protein N	6 2	6 2	6 3	8 1	8 8
Proteose peptone	1 1	1 8	2 7	4 7	8 9
Globulin N	0 8	0 7	1 2	1 3	1 4
β-Lactoglobulin N	7 0	3 1	4 3	3 1	0 9
Albumin N	4 6	3 5	4 7	7 3	7 9

[a] Data taken from Corradini [47]
[b] Determined as described by Aschaffenburg and Drewry [82]

enzymes is determined not only by the severity of heat treatment but also by the nature and quantity of the enzymes present Poor quality milk, which contains increased levels of proteinases of bacterial origin, shows extensive degradation of protein and a short gelation time during storage [29,43,56,107] There is wide variation in the heat stability of proteolytic enzymes of bacterial origin Thermal inactivation data on some proteinases are known[14,59] but such data on all the proteinases is, practically, not possible

Those proteinases that are natural to milk or are of bacterial origin vary considerably in their specific action on individual proteins and are discernible by electrophoretic methods Many of the earlier storage studies on UHT sterilized milk indicated major changes only in the β-casein fraction along with a concomitant increase in the γ-casein fractions that are now known[122] to result from proteolysis of β-casein Electrophoretic patterns presented in Fig 4 illustrate the typical changes in casein fractions during storage of UHT sterilized milk These patterns indicate a decrease in

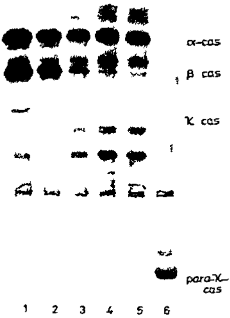

FIG 4 Starch urea gel electrophoresis of casein from UHT sterilized milk stored at room temperature 1 Before sterilization 2 after sterilization 3 stored three months 4 stored five months 5 stored six months 6 rennet treated milk Data from Corradini [47]

the relative concentrations of α_{s1}-, α_{s2}-, β- and κ-caseins and a corresponding increase in γ-casein fractions and para-κ-casein These changes are consistent with the observations of Snoeren and Van Riel[106] that the natural proteinases, which are similar to plasmin in their action, were equally specific for β-casein and α_{s2}-casein although their action on other caseins is slower

The mode of action of these proteinases is influenced by some other factors For example, Harwalkar and Vreeman[34] found that the increase in γ casein was less during storage of UHT concentrated skim milk than in UHT milk (Fig 5) although there was an increase in proteose-peptone and, as pointed by Snoeren and Van Riel,[106] a decrease in α_{s2}-casein The increase in proteose-peptone fraction is also observed in UHT stored milk (Fig 4 and Table 9) and is attributed to the formation of component 5 and component 3 by cleavage of the N-terminal end of β-casein [123,124] The basic fractions observed in Fig 5 appear to be cleavage products of α_{s2}-casein [106]

Numerous studies have indicated that the proteinases of microbial origin survive UHT treatment [29,58–60,107,125–131] The action of bacterial pro teinases on individual proteins is different from that of indigenous

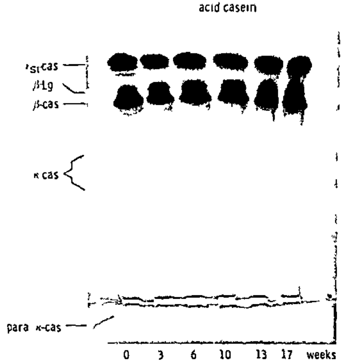

FIG 5 Starch–urea gel electrophoresis of casein from UHT sterilized con centrated skim milk containing polyphosphate Data from Harwalkar and Vreeman [34]

proteinases In contrast to indigenous milk proteinase, bacterial proteinases appear to degrade κ-casein[29 58 125] preferentially However, information regarding the specificity of bacterial proteinases is limited Undoubtedly, the bacterial and the milk proteinases influence the storage behaviour of UHT products to different extents because they differ in their mode of attack on individual proteins Snoeren *et al*[29] observed that a sample of milk that was deliberately contaminated with psychrotrophic bacteria before UHT treatment, gelled on storage sooner than aseptically drawn milk The contaminated milk had the appearance of rennet curd whereas the uncontaminated milk, containing only milk proteinases coagulated without typical gel formation Gelation of both samples was accompanied by extensive proteolysis, the rate of which was higher in contaminated milk In contrast to this, Koops, quoted by Payens,[132] observed gelation of products manufactured from aseptically drawn milk without an accompanying increase in the amount of non protein nitrogen

Storage temperature is another factor that influences the rate of proteolytic action in UHT milk Samel *et al*[70] observed increased breakdown of protein at a higher temperature of storage but were unable to correlate the extent of proteolysis with the time of onset of gelation Samples stored at 4, 20 or 30°C gelled at about the same time (13 months) in spite of varying levels of protein breakdown Furthermore samples stored at 37°C showed the most extensive proteolysis but did not gel

During the storage of UHT sterilized, concentrated milk, considerably slower proteolysis is observed than in UHT treated milk[68 72] Hostettler *et al*[72] observed low levels of protein breakdown and no enzyme reactivation Harwalkar and Vreeman[34] also observed a low rate of protein breakdown as indicated by the decrease in casein nitrogen and increase in non-casein and non protein nitrogen and by gel electrophoresis They further observed that the rates of protein breakdown were unaffected by the addition of orthophosphate or hexametaphosphate Orthophosphate hastened gelation and hexametaphosphate delayed it Similar observations regarding the effect of added phosphates upon changes during storage of unconcentrated milk were made by Snoeren *et al*[29] Interestingly, the gelation time of poor quality milk, sterilized by UHT treatment, was unaffected by the addition of phosphates The reason for this behaviour is not known

Wide variation has been observed by different investigators in the rate and extent of proteolysis during the period in which onset of gelation takes place Data in Table 10 are drawn from different studies and show the variations in the time of gelation and in the decrease of casein content (as percentage of total protein) and increase in non protein nitrogen

TABLE 10

RELATIONSHIP BETWEEN GELATION AND CHANGES IN CASEIN AND NON-CASEIN NITROGEN IN UHT STERILIZED MILK AND CONCENTRATED MILK

Casein (%)			*Non-protein nitrogen (mg/100 ml)*				*Ref*
Initial	*At gelation*	*Change per month*	*Initial*	*At gelation*	*Change per month*	*Time of gelation (months)*	
UHT sterilized milk							
85 2	62 0	7 8	37	80	14 4	3	29
85 0	70 0	1 5	32	52	3 0	10	72
84 7	72 1	2 5	35	50	3 0	5	47
84 3	76 0	0 6	26	60	2 6	13	70
—	—	—	28	120 (78)[a]	10 0	5	28
—	—	—	28	78 (67)[a]	5 6	>7	28
—	—	—	28	54 (58)[a]	2 9	>10	28
Concentrated milk							
85 0	80 0	1 4	24	32	0 2	4	34
89 2	82 0[b]	1 0	21	28	0 1	7	90

[a] The non protein nitrogen values were obtained after nine months of storage The values in parentheses are estimates for the time of gelation, assuming a linear increase of this fraction with time of storage

[b] The percentage of casein remained unchanged during the first $2\frac{1}{2}$ months, then started to decline

(mg/100 ml milk) at gelation time The relative rates, shown as an approximate decrease of percentage of casein per month or increase of non-protein nitrogen per month, correlate well with the gelation time of either unconcentrated or concentrated product, however, there does not seem to be any critical level of protein breakdown at which gelation could be observed The UHT treated, concentrated milk gelled sooner than unconcentrated milk even though the rate and extent of protein breakdown were considerably lower than in milk Also, in UHT milk from different laboratories, which showed approximately the same degree of protein breakdown,[47,72] the time of gelation was markedly different

7. GELATION OF RETORT STERILIZED EVAPORATED MILK

Gelation is not usually a problem during storage of evaporated milk, retort sterilized in containers However, Heintzberger *et al*[23] occasionally

observed gelation in these products They investigated this problem and demonstrated conclusively that gelation was caused by prolonged (2–3 days) cold storage (4 °C) of the concentrate before canning and sterilization The products sterilized after cold storage invariably gelled after about seven months of storage at 28 °C, but those sterilized without cold storage remained liquid for more than 12 months The above investigators tested evaporated milk of different composition and observed gelation only in concentrates with Fat SNF ratio of 9/22 or 10/23 and not in 8/18 standard samples Typical results obtained with 9/22 samples are shown in Table 11 (samples 1 and 2) Additional heat treatment (115 °C for

TABLE 11

AGE-THICKENING AND GELATION OF STERILIZED MILK STORED AT 20 °C[a]

No	*Concentrate fat/SNF (%/%)*	*Holding at 4 °C (days)*	*Treatment*	*Relative viscosity after storage (months)* 0	6	9
1	9/22	0	None	—	—	—
2	9/22	3	None	—	—	+ +
3	9/22	0	Na_2HPO_4 75 g/100 kg	—	—	—
4	9/22	3	Na_2HPO_4, 75 g/100 kg	—	+ +	+ + +
5	9/22	3	Additional heating 115 °C/1 min	—	—	+
6	8/18	0	None	6 7	11 4	13 6
7	8/18	3	None	12 6	75 3	89 1
8	8/18	3	Anticool aging	13 8	81 7	>100
9	8/18	0	Aeration	11 4	15 2	33 0
10	8/18	3	Aeration	9 8	51 5	69 2
11	8/18	0	0 1% H_2O_2	5 4	21 0	48 0
12	8/18	3	0 1% H_2O_2	6 1	>100[b]	>100
13	8/18	3	Deaeration	11 4	59 7	74 8
14	8/18	3	0 2% BHT	7 8	53 1	69 0
15	0/19	0	None	2 5	3 9	>100
16	0/19	3	None	3 8	31 2	>100
17	0/19	0	0 1% H_2O_2	2 8	>100[c]	>100
18	0/19	3	0 1% H_2O_2	3 1	>100	>100

[a] Data for samples 1–5 taken from Heintzberger *et al*,[23] data for samples 6–18 taken from Harwalkar *et al*[22]

The viscosity ratings for samples 1 5 were as follows —, unchanged, +, viscous, + +, strongly viscous + + +, solid gel These correspond to <20, 20–50, 50–100 and >100 relative viscosity units respectively in samples 6–18

[b] The sample had a relative viscosity of 48 6 after 3 months of storage

[c] The sample had a relative viscosity of 4 5 after 3 months of storage

0 5–1 min) of cold-stored concentrate before sterilization provided a slight protection against gelation but did not prevent it (sample 5) Orthophosphate was not considered to be involved in gelation (samples 3 and 4)

Recently, Harwalkar *et al*,[22] working with 8/18 standard evaporated milk and evaporated skim milk (19% TS), have confirmed the unusual observation by Heintzberger *et al*[23] of gelation in retort sterilized evaporated milk The 8/18 standard concentrates held at 4°C for 3 days before sterilization significantly increased in viscosity or gelled within 6–9 months but remained liquid for more than 12 months when sterilized without cold storage

An explanation for the unusual gelation problem was sought by examination of possible involvement of (i) alteration of casein micelles and (ii) oxidation/reduction reactions

(i) Some of the changes in the casein micelles resulting from cold storage are known to be reversed by heating at 55–60°C for 30 min (the so-called 'anticool-aging' treatment) Cold storage of milk is known to delay its coagulation by rennet [133] The delayed coagulation time, presumed to be the result of changes in casein micelles during cold storage, is reversed by 'anticool-aging' treatment Such anticool-aging' treatment was ineffective in preventing gelation and possibly hastened it slightly (sample 8) Therefore, the change in casein micelles leading to storage gelation must be of a different nature from those affecting rennet coagulation time

(ii) Aeration or incorporation of H_2O_2 in concentrated milk, sterilized without cold storage, increased its viscosity during storage (samples 9 and 11 in Table 11) Treatment of cold-stored samples with H_2O_2 accelerated gelation (sample 12), whereas aeration or deaeration of the cold-stored sample did not affect it significantly (samples 10 and 13) Likewise, treatment with antioxidant was ineffective in preventing the age-thickening process (sample 14)

Retort sterilized evaporated skim milk samples were more susceptible to gelation than evaporated milk but the cold-storage treatment and incorporation of H_2O_2 had similar effects on both samples (samples 15–18 versus 11 and 12)

It was observed in these experiments that samples that had become viscous or gelled did not contain micro organisms capable of growing and showed no significant change in pH or proteolysis

The above observations strongly suggest a physicochemical rather than an enzymatic basis for the gelation of retort sterilized evaporated milk The

results demonstrate the significance of oxidizing/reducing type reactions in the gelation phenomenon but the mechanism by which these reactions influence gelation is not clear

8. MECHANISMS OF GELATION

The current state of knowledge is insufficient to make a definitive elucidation of the mechanism of gelation in sterilized milk (or concentrates) during storage Various explanations of the gelation phenomenon have been offered based on changes observed in milk during storage and on the basis of examination of conditions that alter the gelation period However, these explanations are mostly of a speculative nature and need further substantiation A brief discussion of some of the tangible explanations is presented below with the hope that it will stimulate further research

It is now generally accepted that gelation of stored, sterilized milk results from direct interaction between casein micelles and their linkage into a three-dimensional network Although some subunits of casein micelles dissociate from the micelles during storage, there is no evidence to support the concept that gelation results from complete disintegration of the micelles followed by restructuring of the subunits to form a gel [68 132] The interaction between micelles is preceded by changes at the surface of the micelles as a result of which they become more reactive, i e become susceptible to interaction and destabilization The forces that lead to the weakening of the micelle surface are not fully understood as yet Several models have been hypothesized to explain the mechanism of gelation and, in general, the changes that trigger the loss of stability of the casein micelles fall into two categories

(i) changes that arise from proteinase activity (i e with an enzymatic basis),
(ii) changes that arise from non-enzymatic reactions (i e with a physicochemical basis)

8 1. Proteinase Hypothesis

Storage gelation of UHT sterilized milk is accompanied by an increased level of proteolytic breakdown products and by decreased stability to calcium ions [70 72] These changes, also characteristic of rennet coagulation of milk, have led many investigators[28 29 36 47 58 72 125 132] to suggest that the gelation of aged sterile milk (or concentrates) takes place by a

mechanism analogous to that of rennet coagulation in which an enzyme-triggered primary protein degradation step is followed by a secondary aggregation reaction resulting in gelation

The enzyme hypothesis is further supported by the striking resemblance of the pattern of viscosity changes before gelation and the coagulation kinetics of rennet-treated and aged sterilized milks [32,132] On the basis of extensive theoretical treatment, Payens[132] considers that the phenomenon of the initial age-thinning, followed by an explosive growth of the average particle weight, results from the action of a clotting proteinase He rules out non-enzymatic coagulation on the ground that such coagulation would be accompanied by a linear increase in weight-average molecular weight (M_w) with time, t, according to the equation developed by Payens[132] and as simplified by Schmidt [32]

$$\frac{M_w}{M_{t=0}} = 1 + At \tag{1}$$

where $M_{t=0}$ is molecular weight at zero time and A is a constant The enzyme-mediated clotting, which is preceded by an explosive growth of average particle weight, is explained satisfactorily by the following equation [32,132]

$$\frac{M_w}{M_{t-0}} = 1 - A\left(\frac{t}{\tau}\right) + B\left(\frac{t}{\tau}\right)^3 \tag{2}$$

where τ, the so-called enzyme clotting time, is equal to $(K_s V/2)^{1/2}$, V being the rate at which coagulation particles are formed and K_s the coagulation rate constant [134,135]

Equation (2) predicts that when t is very small compared with τ, M_w will decrease but when $t \geq \tau$, the molecular weight will increase explosively This predicted behaviour was observed by turbidity and viscosity measurements also in model experiments on clotting of casein by chymosin or trypsin but the time-scale was considerably smaller [132]

A study of the coagulation kinetics can explain satisfactorily certain forms of gelation in sterilized milk but is not applicable to some other types of gelation, for example in samples of sterilized milk, where gelation was observed without accompanying proteolysis[22,132,136] or in samples where gelation could not be correlated with the rate and extent of proteolysis, as influenced by storage temperature[70,93] or presence of additives such as phosphates, citrates and hydrogen peroxide, etc (see section 5) Also the observation of gelation in evaporated milk that was cold-stored before

retort sterilization,[23,27] and the failure to prevent gelation of HTST sterilized concentrates by an additional retort sterilization treatment,[23] are incompatible with the proteinase hypothesis Furthermore, in a recent study of physicochemical changes during storage of UHT sterilized concentrated casein micelles from aseptically drawn milk, de Koning and Kaper[136] reported typical age-thinning followed by gelation without accompanying proteolysis They controlled proteolysis by addition of trypsin inhibitor

Although proteinase have been isolated from some UHT sterilized milks,[102,103] it has not been possible to demonstrate their presence in other sterilized products, for example in UHT sterilized concentrated milk[104] or 10% cream [105] Furthermore, there is a wide variation in the nature and extent of proteolysis and the occurrence of gelation could not be related to any specific degree of protein breakdown (Table 10) This apparent lack of relationship between gelation and degree of proteolysis could be the result of wide variations in the specificity of the proteinase that are natural to milk or that are of bacterial origin Some of these proteinases lack the highly specific proteolytic action of rennet, which primarily attacks the Phe–Met bond between residue 105 and 106 of κ-casein to yield a (glyco)macropeptide and para-κ-casein In rennet treated milk, 80–90% of κ-casein is degraded before an increase in viscosity is registered[115,137] whereas in sterilized milk (or milk concentrates), only 5–10% of κ-casein is degraded as evidenced by the observation of low levels of macropeptide at the time of gelation [34,70] Presumably, these enzymes affect the surface of the casein micelles differently from rennet to create sites at which the interaction and aggregation reactions occur However, experimental evidence to support such a hypothesis is lacking

8 2. Non-enzymatic Basis for Gelation

The proteinase hypothesis has wide appeal because it provides readily the 'cause' and 'effect' aspects of gelation but the failure to detect a proteinase and to correlate the rate and extent of proteolysis to gelation in some sterilized milk products has led to the suggestion that gelation results from a modification of the surface properties of casein micelles by non-enzymatic, physicochemical processes [24,70,90] Hostettler *et al* [24,72] observed that extensive proteolytic breakdown accompanies the gelation of unconcentrated milk but were unable to observe such proteolysis during the gelation of UHT sterilized concentrated milk [90] They suggested that gelation of concentrated products was affected by the nature and extent of heat induced complex formation between the whey proteins and caseins In

milk subjected to a severe heat treatment, for example autoclaved milk, a complete and irreversible interaction occurs between whey protein and casein and the resultant complex protects the micelles from further changes and interaction with each other during storage The milder heat treatment, as in UHT treatment by direct steam injection, leads to the formation of an incomplete and reversible complex that does not protect the micelles from further changes and interaction during storage A similar suggestion was also made by Graf and Bauer[13] who consider the UHT heat treatment to be insufficient to 'complete the heat-induced micellar transformation The subsequent rapid cooling "freezes" an unfinished micellar state which is unstable' The incomplete nature of the complex is evident from the experimental observation of residual undenatured whey proteins in UHT sterilized milk, but the reversible dissociation of the complex, as suggested by Hostettler *et al*,[24 90] has not been substantiated The hypothesis suggesting protective action of the complex against gelation is less tenable because gelation was observed in some evaporated milk samples that were cold-stored before sterilization by the retort method [22 23] In these samples the sterilization heat is sufficient to form an irreversible complex Furthermore, increasing the level of whey proteins,[15] which presumably increases the degree of the complex formation, hastens gelation in HTST sterilized, concentrated milk

A chemical modification of casein micelles by Maillard-type[46 89 109 113] reactions or by disulphide bonding[67 138] has been implicated in the mechanism of gelation Andrews and Cheeseman[46 109 113] suggested that the gelation of UHT sterilized milk is linked with the polymerization of casein and whey proteins through Maillard-type reactions which are promoted as the temperature of storage is increased However, the failure to observe gelation during storage of sterilized milk at temperatures above 35 °C is not consistent with their suggestion Substituting sorbitol for lactose did not prevent gelation of UHT sterilized concentrated suspensions of casein micelles [136] Others[70 72] have suggested that the blockage of ε-NH_2 groups of lysine residues by interaction with lactose or its degradation products prevents casein micelles from interacting and gelling These reactions presumably modify the charge of the casein micelles but their significance in the mechanism of gelation is not clear as yet

Modification of the surface properties of casein micelles may also be caused by partial dissociation of the micelles during storage (see section 6) This process of dissociation or 'shedding' could expose regions on the surface of casein micelles that promote interaction between casein micelles However, the forces that lead to the 'shedding' of sub-units are not known

The reaction of the exposed regions could result from slow conformational changes at the surface of the casein micelles [34 70,133] The deformation at the surface of the casein micelles observed during storage by electron microscopy[34 38,71] would tend to support this notion but more definitive experimental substantiation of such conformational changes at the surface of casein micelles is needed

Another hypothesis of gelation, based on non-enzymatic modification of casein micelles, is considered in terms of changes in free energy [13] The micelles in sterilized milk are perceived as being in a metastable state with a high surface potential During storage, a progressive, spontaneous transformation of the micelles from a 'high' potential to more stable micelles with lower surface potentials occurs by random potential jumps The decrease in potential energy of some micelles creates a potential difference which promotes aggregation of the micelles, depending upon the probability of contacts and the number of low-potential micelles, both these increase with time Initially the aggregation is insignificant but when the average surface potential of the micelles attains a critical level, aggregation becomes evident as a pronounced increase in viscosity [13] The stabilizing influence of an intense heat treatment and of additives is believed to result from a condition of the micelles in which changes in the surface potential and racemization of the micelles are reduced The factors that cause stabilization against gelation are believed to enhance such changes However, such a hypothesis based on potential energy changes is highly speculative but merits further consideration through experimental approach

9. CONCLUSION

Although the fundamental understanding of the mechanism of gelation in sterilized milk (or concentrates) is not adequate at present, there are several empirical approaches that are useful in extending gelation-free shelf life of sterilized products in practical situations

(i) *Assurance of good-quality milk in the manufacture of sterilized products* Microbial contamination should be kept to a minimum by maintaining good hygienic conditions throughout production and processing of milk by minimizing the cold storage of raw milk and by thermization treatment of milk before cold storage

(ii) *Adequacy of heat treatment during forewarming and sterilization* What constitutes adequate heat treatment is difficult to determine

because of wide variation in the quality of raw milk processed in different geographic regions and at different times Generally, slightly more severe heat treatment than is necessary to achieve commercial sterility is beneficial in delaying gelation However, such beneficial effects must be weighed against undesirable flavour changes

(iii) *Maintenance of lower temperature of storage ensures longer gelation-free shelf life* The sterilized products should be stored, where possible, at cooler temperatures ($<20\,^\circ C$) Storage at refrigeration temperatures is beneficial from the point of view of flavour changes and gelation but it nullifies the primary advantage of UHT sterilized products, namely, the possibility of storage at ambient temperatures

(iv) *Incorporation of additives* Polyphosphates, thus far, appear to offer best protection against gelation

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Chapter 8

CHANGES IN THE PROTEINS OF RAW MILK DURING STORAGE

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1. INTRODUCTION

Milk technology has a broad biochemical background In particular, the presence of proteolytic enzymes is closely correlated with the technological properties of milk and the quality of dairy products Besides heat treatment, storage of bulk milk at 2–6 °C is the most suitable procedure to avoid undesirable quality changes caused by contaminating micro-organisms The introduction of cold storage of bulk milk has been necessary for economic and practical reasons related to centralization in the dairy industry It has, however, resulted in a number of unexpected problems The fermentation properties of cooled raw milk are significantly different from those of fresh raw milk This has been found to be partially due to a change from mesotrophic to psychrotrophic micro-organisms and partially to proteolytic reactions The resulting problems during fermentation, e g proteolysis and lipolysis instead of lactic acid formation, have been solved by pre ripening milk using mesotrophic starter cultures

Changes in the properties of bulk milk stored at 2–6 °C may require important modifications to be made in the normal processing, e g during cheesemaking Coagulation time and curd formation, in particular, are influenced by cold storage and are in some cases delayed as much as 100 % Systematic investigations have shown that these differences are not due to changes in the contaminating microflora but to changes in the milk itself

The effects of cold storage on the processing parameters of raw milk are related to the micellar character of the casein fraction of the milk proteins

Several authors have described the dissociation of micellar components, especially of the highly hydrophobic β-casein, during cooling of raw milk, the equilibrium between the milk serum and the micelles. While the α_s- is much less affected by temperature, β-casein dissociates extensively from the micelles into milk serum at low temperatures.

Studies on milk serine proteinases have revealed a similarity between the temperature-dependent association of these enzymes with micelles and that of β-casein. Transfer of the trypsin-like milk proteinases and β-casein into the milk serum during cooling provides a mechanism for γ-casein formation. It is now well established that the γ-caseins are proteolytic fragments of β-casein and that the micelle-associated proteinases show a high specificity for β-casein. Therefore, an increase in the γ-casein content during cooling of raw milk may be expected, and estimations of the γ-casein content could be useful for evaluating pretreatments of raw milks in relation to their subsequent processing.

Therefore, relationships between proteinases and proteinase inhibitors in milk and the status of the caseins and their dissociation and solubility behaviour during cold storage of bulk milk, including subsequent proteolysis, e.g. of β-casein to the γ-caseins, are directly related to the processing properties of milk.

2. THE PROTEINASES AND PROTEINASE INHIBITORS OF MILK AND THEIR PHYSIOLOGICAL IMPORTANCE

Enzymes are good indicators of changes in milk.[1] In recent years numerous papers on milk proteinases have appeared in the literature and have been summarized in a series of reviews and comprehensive articles.[2–23] The first indication of naturally occurring proteolytic enzymes in milk was published in 1879.[7] Most of the investigations have been concerned with differentiation of indigenous milk proteinases from proteinases produced by contaminating micro organisms, purification and properties of indigenous milk proteinases, biosynthesis and direct comparison of these proteinases with plasmin and also with the technological aspects of the activity of indigenous proteinases in milk.[2–28]

Most of the work on indigenous milk proteinases has been done on the trypsin-like enzymes which are associated with the caseins.[6–23] These trypsin-like enzymes belong to the group of serine proteinases[3,4,21] and hydrolyse β-casein predominantly.[2,11,29–34] Recent results indicate that in addition to the trypsin-like enzymes, milk also contains a chymotrypsin-

like enzyme [25 26 35] Furthermore, an acid proteinase, which is associated with β-casein,[32 36] and a neutral enzyme, which has a high specificity for α_{s2}-casein, have been reported [37 38]

Aminopeptidase activity, known to be present in bovine milk, has been characterized recently [15] While the endoproteinases are associated with the casein micelles, the aminopeptidase activity is found in the milk serum There is one report[3] on the association of a plasmin like enzyme with the fat globule membrane

Most of the purification work has been performed with conventional biochemical methods such as acid extraction of casein, ammonium sulphate precipitation and/or chromatographic techniques [2 6 7 11 14 25] Questions related to the origin of milk enzymes have centred on similarities between isolated trypsin-like enzymes and plasmin prepared from blood serum [3 17 19 29 39] In most cases, whole or individual caseins have been used as substrates for determination and characterization of proteolytic activities β Casein has been the preferred substrate, primarily because of its involvement in the formation of γ casein by trypsin-like enzymes

3 RECENT DEVELOPMENTS

3 1. Determination of Proteolytic Activities

Casein is one of the most common substrates for the evaluation of proteolytic activities,[6 7 10 24 37 40] primarily because of its availability, stability under storage conditions, and its random, non helical structure which allows its application with most proteolytic enzymes without preceding denaturation [41] The extent of proteolysis is generally determined by measuring absorption at 280–295 nm of the clear filtrate remaining after acid precipitation of unaltered casein This adsorption, e g the so-called tyrosine value, is attributable to the presence of aromatic amino acids in the acid-soluble peptide fragments Direct comparison of the values obtained in this manner with Kjeldahl nitrogen, or ninhydrin determination of free amino groups, indicates that there are several problems associated with measurement of proteolytic activities in this manner,[11 41] particularly if individual caseins, e g β-casein, are used

β Casein is the preferred substrate for characterization of milk serine proteinases because the peptide bond Lys28–Lys29 is highly susceptible to proteolysis and leads to the γ-casein However, since the resulting soluble peptide fragment of β-casein (residues 1–28) contains no aromatic amino-acids, no proteolytic activity is detected by measuring absorption at

280–295 nm For this reason, a procedure which determines the free amino groups formed during proteolysis (e g ninhydrin reaction) gives much more reliable results[41] Titration procedures and Kjeldahl nitrogen determinations have also been used to follow proteolysis in these investigations

Additional problems arise during evaluation of the kinetic properties of purified enzymes Only apparent kinetic parameters can be obtained since a relatively large number of peptide bonds are susceptible to proteolysis by trypsin-like proteinases (e g β-casein contains 12 lysyl and 4/5 arginyl bonds) The proteolytic specificity is highly dependent on the peptide environment around these bonds In the case of β-casein, there are only three specific cleavage points, hydrolysis of which results in formation of the three γ-casein peptides[42–44]

In order to compare the kinetic parameters for various enzymes, substrates containing single specific peptide bonds are required For this purpose special synthetic, chromogenic derivatives, the 4-nitroanilides of free and substituted amino-acids, have been developed as substrates for endoproteinases and aminopeptidases[45–47] The specificity of each substrate is derived from the amino-acid involved Eleven such substrates have been used in the course of investigations to evaluate kinetics and to characterize proteolytic activities Proteolysis is quantified by monitoring the release of 4-nitroaniline measured by absorbance at 405 nm These substrates are also suitable for monitoring enzyme isolation With trypsin-like enzymes and plasmin, lysyl and arginyl derivatives have been found to be especially useful

3.2. Purification of Trypsin-like Enzymes from Milk and Plasmin from Blood Serum

Relatively pure preparations of the trypsin-like enzymes in milk have been obtained using conventional biochemical methods[2 7 25 48] Purification of plasminogen and plasmin has been performed by affinity chromatography[19 29 49–52] resulting in highly purified enzyme preparations The association of the trypsin-like enzyme system with native casein micelles has been confirmed[2 11 32 48] The micelles have been sedimented by ultracentrifugation and the enzymes extracted with sulphuric acid[11] Purification by ion exchange chromatography has revealed that this enzyme system consists of two serine proteinases with different specificities for lysyl– and arginyl–peptide bonds[11 14 33 48]

Since homogeneous enzyme preparations are needed for direct comparison of kinetic properties, affinity chromatography on lysine–Sepharose

was used to isolate trypsin-like enzymes and plasminogen/plasmin under almost identical conditions from milk and blood serum, respectively, obtained from the same animal.[49,54] Lysine bound to Sepharose by the α-amino group (achieved by coupling at pH 8·9 to exploit the difference in the pK values of the two amino groups of lysine) simulates the weak plasmin inhibitor, 6-aminohexanoic acid.[53] Elution was performed at pH 7·2 with sodium acetate buffer containing 0·15 M NaCl and 0·1 M lysine.[20,53–55] The results confirmed earlier data, obtained using ion exchange chromatography,[34] that there are two serine proteinases in the proteinase preparation obtained from casein micelles (Fig. 1). One binds to lysine–Sepharose like plasminogen/plasmin and will be called plasmin-like enzyme or milk proteinase I. The second enzyme, which does not bind to lysine–Sepharose, will be called thrombin-like enzyme or milk proteinase II.

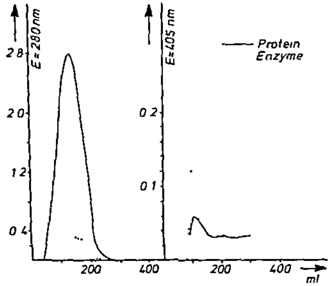

FIG. 1. Isolation of two serine proteinases by affinity chromatography on lysine–Sepharose from the trypsin-like enzyme fraction of milk (ref. 20, with permission of *Milchwissenschaft*).

Affinity chromatography results in a 180–220-fold increase in the specific activity of milk proteinase I and plasminogen. The plasminogen/plasmin fraction was resolved into enzyme and zymogen components by gel filtration chromatography. For kinetic evaluations, the highly purified enzyme preparations were stabilized by partially hydrolysed gelatin, which does not influence the kinetics because it contains no lysyl–or arginyl–peptide bonds.

3.3. Direct Kinetic Comparison of Plasminogen/Plasmin with the Two Serine Proteinases from Milk

Preliminary data on milk proteinase prepared from casein micelles showed highly specific proteolysis of β-casein and only non-specific degradation of α_s- and κ-caseins,[24,33 47] in good agreement with the relatively high concentration of γ-casein in milk [30–33,59 60] Direct kinetic comparisons between highly purified, stabilized plasminogen/plasmin and milk proteinases I and II prepared from the same animal, on D,L-benzoyl-lysine-4-nitroanilide (D,L-BLPA) and L-benzoylarginine-4-nitroanilide (D,L-BAPA), which are specific substrates for trypsin-like serine proteinases, should indicate whether one of the milk proteinases is identical with plasmin

Addition of urokinase, a highly specific plasminogen activator, increases the activity of milk proteinase I preparations, indicating that it contains plasminogen Moreover, the activity of preparations of this enzyme is increased by addition of glycerol, a similar effect has been reported for plasminogen and plasmin [61–66] pH optima obtained for milk proteinase I and plasmin on D,L-BLPA are between 7 5 and 7 8, which is typical for serine proteinases Yamauchi *et al* [25,33 40] obtained pH optima of about 8 0 for plasmin and an enriched milk proteinase using casein as a substrate

Plasmin shows much higher affinity for lysyl–peptide bonds than thrombin, while specificities are reversed for arginyl–peptide bonds [67 68] Both milk proteinase I and plasmin show comparably higher activities on D,L-BLPA, while milk proteinase II, which does not bind to lysine-Sepharose, is more active on D,L-BAPA This is a good indication of similarity between plasmin and milk proteinase I Michaelis constants (K_M) on D,L-BLPA and D,L-BAPA obtained for all enzymes investigated were in the region of 1 mM

Inhibition patterns obtained for milk proteinase I and plasmin with Kallikrein–trypsin inhibitor and with blood serum, known to contain trypsin inhibitors, were practically identical, clearly indicating that milk proteinase I and plasmin are closely related and may be considered to be identical Further evidence of identity is provided by the identical inhibitory patterns caused by the weak inhibitors present in milk serum, by 6 aminohexanoic acid[17] and by chlorides of Ca, Cu, Zn and Co [17 29 69] Similar specificities have been reported for the two enzymes using casein as substrate [19 25 33] These similarities clearly indicate that milk proteinase I and plasmin are identical, while milk proteinase II shows thrombin like activity with higher specificity for arginyl–peptide bonds

3.4. Characterization and Comparison of Proteolytic Enzymes with 4-Nitroanilides

4-Nitroanilide derivatives of several amino-acids are available to detect and characterize proteinases,[45–47,70] differentiation between endoproteinases and aminopeptidases is also possible by using substituted and free amino-acid-4-nitroanilides Eleven 4-nitroanilides have been used to characterize and to compare the proteolytic activities present in casein micelles, milk serum and in blood serum [15] The relative proteolytic activities at pH 7 8 are shown in Fig 2

Micelle-associated enzymes (Fig 2a) show typical trypsin-like activities in that primarily lysine- and arginine-4-nitroanilides are hydrolysed Entirely different patterns are obtained with bovine milk and blood sera

	Substrate	*Abbreviation*
1	Glycine 4-nitroanilide	Gly-4-NA
2	L-Alanine-4 nitroanilide	L-Ala-4-NA
3	L-Leucine-4-nitroanilide	L-Leu-4-NA
4	L-Phenylalanine-4-nitroanilide	L-Phe-4-NA
5	L-Tyrosine-4-nitroanilide	L-Tyr-4-NA
6	L-Lysine-4-nitroanilide	L Lys-4-NA
7	N-Actyl-L-alanine-4 nitroanilide	N-Ac-L-Ala-4 NA
8	Glutaryl-L-phenylalanine-4-nitroanilide	Glu-L-Phe-4-NA
9	N-Acetyl-L-tyrosine 4-nitroanilide	N-Ac-L-Tyr-4-NA
10	Nα-Benzoyl D,L-lysine-4-nitroanilide	D,L-BLPA
11	Nα-Benzoyl-D,L-arginine-4-nitroanilide	D,L-BAPA

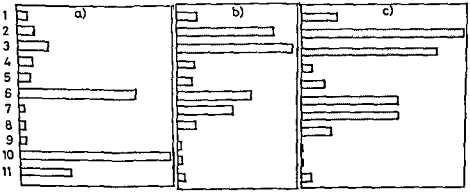

FIG 2 The relative proteolytic activities of bovine proteinases (a) from the casein micelles, (b) from milk serum and (c) from blood serum (ref 15, with permission of *Milchwissenschaft*)

(Fig 2b and c) which contained significant aminopeptidase activities, particularly for alanine-, leucine- and lysine-4-nitroanilides Only non-specific proteolysis of D,L-BAPA and D,L-BLPA, which are typical substrates for trypsin-like endoproteinases, was found in bovine milk and in blood serum Direct comparison of milk serum with blood serum from the same animal showed extraordinary homology in the proteolytic profiles except that concentrations of enzymes were significantly higher in the blood serum This indicates that these might be directly transferred from the blood into the milk This has been demonstrated for bovine serum albumin and is obviously possible for plasmin also

3.5. The Proteinase Inhibitors of Milk

While the presence of indigenous milk proteinases has been the subject of many investigations, relatively few data are available on the proteinase inhibitors and were predominantly obtained for trypsin inhibitors in bovine colostrum[71-75] which contains high concentrations of trypsin inhibitors A trypsin inhibitor with an isoelectric point at pH 4 2 has been isolated from colostrum and crystallized [74 75]

Bovine colostrum inhibitor, which consists of five iso-inhibitors, contains 67 amino-acids and is different from the pancreatic trypsin inhibitor although 21 of the amino-acids are in the same position in the sequences of both types of inhibitors [71-73]

The level of trypsin inhibitors in bovine milk is quite low 1 ml of milk can inhibit 200 μg trypsin to the extent of 95% Heating above 75°C causes partial inactivation of the inhibitors

The proteinase inhibitors of milk have been purified by molecular sieve chromatography[14] and characterized against various proteinases Bovine milk contains inhibitors not only against serine proteinases, e g trypsin, but also against SH-proteinases such as ficin Separation of the two trypsin inhibitors from the indigenous milk serine proteinases was achieved at pH 2 where the trypsin inhibitor–trypsin complex is supposed to be fully dissociated [14 76] The two trypsin inhibitor fractions of milk differ in molecular weight, the high molecular weight fraction amounts to 11–20% of the total inhibitory capacity

Fellenberg and Horber[77] were able to differentiate between the trypsin inhibitors in bovine milk and colostrum According to their results, colostrum contains four trypsin inhibitors, three of which are soluble in perchloric acid, while milk contains significant amounts of the α-1-proteinase inhibitor of blood serum as well as traces of α-2-macroglobulin

They also discussed two aspects of the physiological significance of the inhibitors, namely protection of antibodies against digestion and inhibition of lysomal enzymes in mammary cells

4. DISSOCIATION OF THE MICELLAR SYSTEM DURING COLD AGEING

Raw milk may be defined as a polydisperse system which has a temperature of 38 °C directly after milking This extremely heterogeneous system is not very stable, creaming and microbiological deterioration are well-known changes which take place during storage Storage of bulk milk at 2–6 °C is one of the most suitable procedures to avoid undesirable quality changes by inhibiting the growth of contaminating micro-organisms, no problems were expected concerning the microbiological, physical and chemical status of raw milk

However, the microflora of raw milk are altered by bulk storage at 2–6 °C [78 79] For cheese manufacture the problem may be solved by including a pre-ripening step, using special cultures, into processing schedules

In addition to changes in the microbiological status of raw milk, several physical and chemical alterations occur, including changes in the rennet coagulation time and curd firmness, and reduced yields of cheese, as well as increases in γ casein content and flavour defects [84–104] These problems are due to reversible and irreversible changes in the physical and chemical status of raw milk While reversible changes are concerned with protein and salt equilibria, irreversible changes are due to proteolysis Actually, raw milk stored at 2–6 °C should be considered as 'processed' milk and as a raw material with altered characteristics [81 82] As early as 1912 Muller[83] described how during cold storage for prolonged periods the renneting properties of milk were changed and since that time numerous investigations have been concerned with the factors which are changed in raw milk during storage at 2–6 °C [84–104 110]

4.1 Dissociation of the Casein Micelles

Many factors including pH, calcium phosphate/citrate and the caseins themselves can affect the protein equilibrium in milk and micelle stability Schwarz *et al* [105] reported that cold storage reduced the calcium and phosphate content of milk ultrafiltrate by 15–25%, this claim was supported by Fricker [84] However, Davies *et al* [85] found that soluble

calcium and phosphate increase on cold storage due to dissolution of colloidal phosphate These conclusions were supported by Quist[100] and Wiechen *et al*,[106] who used ^{45}Ca to measure the distribution of calcium between the micelle system and milk serum, during cold storage the calcium content of the serum increased by 8 8% Further, the salts equilibrium is very much affected by changes in pH, which is about 0 3–0 4 units higher at 2–6°C compared with 38°C [80]

Changes in the calcium phosphate/citrate equilibrium are directly correlated to the stability of the casein micelles and the protein equilibrium,[96-102 106 107] but most measurements of the protein equilibrium have been performed without considering the salt equilibrium Several investigations have been performed on the contents of micellar and soluble casein, and on changes in these during cold storage as a function of temperature and time Although variable results have been obtained, due mainly to variations in the experimental conditions, it is generally agreed that soluble casein concentration increases substantially during storage at 2–6°C, up to 42% of the total casein is dissolved after storage for 48 h at 4°C [104] The degree of dissociation is directly correlated to protein content and micellar dissociation is fastest during the first 6 h of cold storage, e g at 4°C the protein content of milk serum prepared by ultracentrifugation (198 000 g, 120 min, 4°C) increased from 0 73% to 0 9% and 0 93% after 6 h and 24 h respectively [108] This is in good agreement with the findings of several other authors [91 94 96 100-104]

In addition to the overall dissociation of proteins from the micelles into the milk serum, the amounts of individual caseins solubilized have been determined [87 96-104 108] Again, variable data have been obtained due to large variations in the experimental conditions In Fig 3 a typical example of the temperature-dependent concentration of α_s- and β-caseins in bovine milk serum after 4 h of storage is demonstrated [58] While the equilibrium of α_s-casein between serum and the micelles is almost independent of temperature, β-casein dissociates to a large extent from the micelles into the serum at low temperature This may be due to the highly hydrophobic character of β-casein and its open-chain structure resulting from its high content of proline [26] During longer storage times the α_s-/κ-casein equilibrium is also affected and both caseins are dissolved to some extent into milk serum,[104] but at lower concentrations than β-casein

4.2. Changes in Technological Properties

The above-mentioned alterations in the protein and salt equilibria in milk during cold storage definitely change its technological properties In

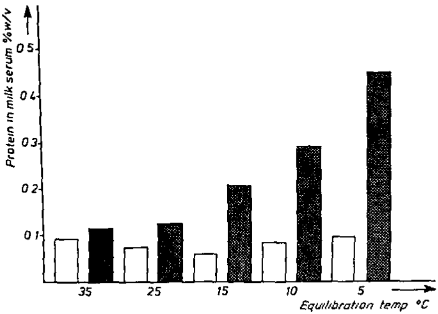

FIG 3 The concentration of α_s-casein in milk serum after storage for 4 h at various temperatures The micellar protein was sedimented by ultracentrifugation (190 000 *g*, 2 h) at the storage temperatures Shaded, β-casein, unshaded, α_s-casein (ref 58, with permission of *J Dairy Research*)

particular the cheesemaking parameters (rennet coagulation time, curd firmness and whey drainage) are influenced to such an extent that processing schedules have to be changed [82 88 96–102 109] Losses in cheese yield of up to 10% have been reported [97] Attempts have been made to re-establish the properties of the original raw milk, for instance by pre-ripening,[11] addition of calcium chloride[95 110] and adjusting the pH [102] Besides, heat treatment seems to be a useful method of causing readsorption of solubilized casein on to the micelles in order to re-establish the original cheesemaking properties of raw milk [99 108] Thermization at 60 °C for 30 min results in a protein content in the milk serum equal to that of the original fresh raw milk, indicating that a protein system needs long-term treatment for re-establishment of equilibrium due to the macromolecular character of its components [99]

5. PROTEOLYSIS IN MILK DURING COLD STORAGE

The presence of proteinases in milk is associated with several technological problems occurring during milk processing and storage Among these are gelation during storage of UHT milks, proteolysis and associated flavour

and textural defects in cheese or in milk powder, and the formation of γ- and λ-caseins from β- and α_{s1}-caseins, respectively [5 28 31 58,114 116 122] Unlike the reversible changes in casein and milk salts equilibria, proteolysis causes irreversible alterations in milk during storage

The proteinases may be indigenous, as described in the first part of this paper, or they may be produced by a contaminating micro-organism [21] There are several parameters indicative of proteolysis in milk non-protein nitrogen content, bitter peptides, γ- and λ-caseins, and empirical ones, such as off-flavour caused by peptides, gelation and changes in viscosity Preliminary data on proteinases prepared from casein micelles show highly specific proteolysis of β-casein to γ-caseins and only non-specific degradation of α_{s1}- and κ-casein [10-16 32-35] Snoeren and Van Riel[111] described a highly specific degradation of α_{s2}-casein by trypsin-like milk proteinases

5.1. Proteolytic Degradation of β-Casein

By sequence analysis it has been demonstrated that the γ-caseins are *C*-terminal fragments of the corresponding β-caseins [31 42] The γ-casein concentrations in various milks vary from 2 to 10%,[30 31 33 112] suggesting that these concentrations are influenced by environmental parameters such as storage conditions

Equilibrium studies on milk proteins revealed that β-casein dissociates from the micelles into milk serum on cooling During purification of the trypsin-like milk proteinases I and II, Reimerdes and Klostermeyer[11] found that these enzymes are proportionally released with β-casein into the serum Model experiments have confirmed that proteolysis of β-casein by plasmin, trypsin or trypsin-like milk proteinases results in formation of γ-casein and phosphoproteins [24 30 31 56 57] Therefore, high concentrations of γ-casein are as anticipated in view of the physical chemistry of the milk protein system Evaluation of γ-casein formation during storage of raw milk is demonstrated in Fig 4 [58] The γ-casein content was estimated by a simple extraction procedure with organic solvents γ Caseins are soluble in organic solvents because they are even more hydrophobic than β-casein, having lost the hydrophilic *N*-terminal phosphopeptides during proteolysis From a series of solvent systems, the combination of 1-propanol and diethyl ether (2 1, v/v) was found to give best results After incubating the milk at a given temperature, the casein fraction is precipitated at pH 4 6, sedimented by centrifugation, resuspended for 30 min in the above solvent system, filtered and the soluble fraction recovered by evaporation The residual proteins were determined by the Kjeldahl method and identified by polyacrylamide electrophoresis Typical results for γ-casein formation in

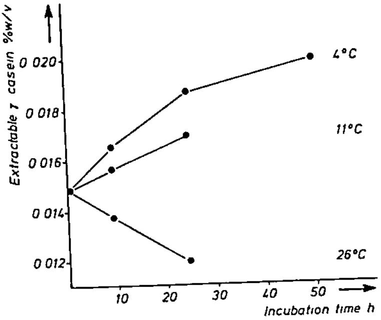

FIG 4 Amount of γ-casein extractable in 1-propanol diethyl ether (2 1, v/v) from milks at different storage times and temperatures The acid-precipitated casein was suspended in the solvent system for 30 min After filtration, the solvent was evaporated and the protein content of the residue determined by the Kjeldahl method (ref 58, with permission of *J Dairy Research*)

raw skim milk at 4, 11 and 26 °C are shown in Fig 4 The pattern for storage at 26 °C shows a significant decrease in the concentration of γ-caseins, which could be due to further degradation by aminopeptidases present in the milk serum [15] Further, less specific degradation by the trypsin-like milk proteinases might be also possible because they are derived via cleavage of three bonds in the β-casein molecule, viz 28–29, 105–106 and 107–108, while β-casein contains at least 15 peptide bonds with lysyl and arginyl residues, which can be hydrolysed by trypsin-like enzymes During cold storage there is a significant increase in γ-casein formation, which is greater at 4 °C than at 11 °C This is in contrast with what would be expected on the basis of normal enzyme kinetics and can be explained by the dissociation of the substrate (β-casein) and the enzyme (milk proteinase) from the casein micelles at low temperatures, followed by proteolysis This is in good agreement with the results of Rollema and Visser[123] who were able to remove a trypsin-like enzyme from casein by specific lysine extraction, demonstrating the high binding capacity for lysyl residues At higher temperatures, e g 26 °C, β-casein and the enzymes are partly immobilized by hydrophobic association with β-casein, allowing only limited proteolysis However, this is only a partial explanation since γ-casein may account for up to 10 % of total casein in some fresh (unstored) raw milks

which suggests that there may be some special mechanism for proteolysis during casein and micelle formation in the udder Hence, these results show that cooling raw milk can cause appreciable changes in its casein composition, especially of the β-casein, and are supported by numerous papers concerning *in vitro* digestion of β-caseins by trypsin-like enzymes, e g by plasmin, resulting in γ-caseins and the corresponding phosphopeptides [31 111–123]

Relatively few data are available on the *N*-terminal phosphoproteins which are formed during β-casein degradation Groves *et al*,[31] Kolar and Brunner[59] and Andrews[124 125] pointed out that they were found in the proteose-peptone fraction of milk These results were confirmed with a pure reference phosphopeptide, obtained by *in vitro* model proteolysis of β casein by plasmin or trypsin [56 57] With such reference proteins quantitative measurements of phosphopeptide, as well as of γ-casein formation, by electrophoresis and densitometry were performed [57]

Beside the formation of γ-caseins, there are two reports on a specific proteinase which degrades β-casein at an acidic pH optimum [32 36] While direct occurrence of this enzyme with the β-casein fraction was demonstrated,[36] it mainly hydrolyzes α_s-casein

5.2 The Proteolytic Degradation of α_s-Casein and κ-Casein

While there is considerable information on γ-casein formation from β casein, few results exist on the degradation of α_s- and κ-caseins by the indigenous milk proteinases [113–115 117–120] Aimutis and Eigel[113] showed in model experiments that the λ-caseins are formed by proteolysis of α_{s1}-casein by plasmin The close association of λ-casein with α_s-casein may be responsible for the paucity of information available on these fragments Snoeren *et al* [37 38 111 115] reported on the specific proteolysis of α_{s2}-casein by trypsin-like milk proteinases and found equal specificity for α_{s2}-casein and β-casein

Only *in vitro* experiments have been made on κ-casein degradation by the trypsin like milk proteinases resulting in so-called ε-casein [6 23 126 127] Proteolysis appears to be very unspecific and only slow degradation was found

5 3. The Technological Significance of Proteolysis in Milk

Most investigations have dealt with the heat stability of milk and milk products Especially during long term storage, the influence of the indigenous proteinases in sediment formation or gelation[21 103 111 115 116] is of importance There are differences concerning the inactivation of the

milk proteinases due to varying UHT treatments [103,115] The influence on cheesemaking properties has been discussed and proteolytic reactions may be involved with off-flavour development, especially during cheese ripening [10 111]

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Chapter 9

NUTRITIONAL ASPECTS OF MILK PROTEINS

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1. INTRODUCTION

One of the major characteristics of the nutritional situation during the neonatal period in mammals is the fact that the offspring has to rely upon a single source of nutrients, milk. Consequently, never in life is there less possibility to compensate for any lack of nutrients in the diet. Furthermore, during this period there is very pronounced growth and maturation of tissues which creates an increased demand for essential nutrients. At the same time there is a reduced tolerance for deviations in food intake due to the immaturity of the liver and kidneys, both of which play essential roles in the metabolism and excretion of metabolites. Consequently it has, rightly or wrongly, been assumed that the milk composition of any mammalian species is the definitive indicator of the neonatal requirements of the offspring. It is quite obvious from analyses that there are great variations in the composition of milks from various species[1] (Table 1). It is therefore logical to assume on a teleological basis that the composition of milks of different species represents the optimum composition of nutrients required during the newborn period of that species. It was anticipated that there would be a relationship between the rate of growth of the offspring and nutrient density, i.e. the amount of essential nutrients per energy unit.[2,3] Bernhart[4] demonstrated a linear relationship between the percentage of protein energy in milk and the growth rate of the newborn, expressed as the logarithm of number of days to double birth weight, when milks from nine species were compared.

In the industrialized world, dairy products play an essential role in the human diet and milk proteins constitute 20–30 % of total dietary protein

TABLE 1

COMPOSITION OF MILKS OBTAINED FROM DIFFERENT MAMMALS AND GROWTH RATE OF THEIR OFFSPRING

Species	*Total protein*[a]	*Casein (% total protein)*	*Fat*[a]	*Lactose*[a]	*Ash*[a]	*Days required to double birth weight*
Man	0 9	30	3 8	7 0	0 2	180
Goat	2 9	86	4 5	4 1	0 8	12
Cow	3 4	80	3 7	4 8	0 7	47
Water buffalo	3 8	84	7 4	4 8	0 8	
Indian elephant	4 9	39	11 6	4 7	0 7	
Sheep	5 5	84	7 4	4 8	1 0	10
Rat	8 4	76	10 3	2 6	1 3	6
Northern fur seal	8 9	52	53 3	0 1	0 5	
Blue whale	10 9	66	42 3	1 3	1 4	10

Source Jenness[1] with some slight revision
[a] Expressed as g per 100 g whole milk

Milk represents one of the most complete single food items and the use of various dairy products in the human diet without doubt takes advantage of their content of essential nutrients Milk products also function as high-value supplements to many diets in different regions of the world

When discussing the nutritional significance of milk for development and future life of the offspring, as well as in the human diet, a number of questions arise

(i) Is there a difference with respect to the various components of the milk, i e are some constituents more specific for the species than others and if so, does it then mean that they are also more essential for the development of the offspring?

(ii) What evidence do we have that milk is the most relevant source of nutrients? During what age period does it seem to be the optimum food? Are milk products always valuable constituents in the human diet?

(iii) What do we know regarding the stability of the composition of milk? What do the physiological variations in milk composition mean nutritionally?

(iv) What do we know about the significance of various environmental factors on milk composition, i e maternal diet, drugs, contaminants, environmental pollution?

Based on observed differences in the composition of milks from various species, Jenness[1] divided milk components in the following groups

(i) Organ- and species-specific,
(ii) Organ-specific but not species-specific,
(iii) Not organ-specific but species-specific,
(iv) Neither organ- nor species-specific

It can be assumed that those components which are both milk- and species specific are of greatest nutritional and metabolic interest This hypothesis is especially valid with respect to milk proteins

No doubt the proteins in milk represent some of the most essential nutrients as the availability of essential amino-acids is a necessary requisite for the formation of new protein during the rapid growth period after birth All milks analysed to date contain considerable amounts of protein although its concentration varies between 1 and 20% when milks from various species are compared [5] There is also very pronounced variation in the number and types of proteins present in milks from different species

Milk proteins have been intensively studied throughout the years by protein biochemists [6] Thus, Mulder,[7] who originally gave proteins their name, devised one of the first acid precipitation methods for the separation of bovine casein Originally casein was assumed to be the only or major specific milk protein while most of the less abundant milk proteins were thought to be derived from blood Later extensive studies have shown that many of the non-casein proteins in milk are also synthesized in the mammary gland and must be considered as milk-specific [6 8 9] The proteins of bovine milk have been more widely studied than those of any other species It is therefore not surprising that the nomenclature of milk proteins is still based on the characterization of bovine milk proteins [10]

It is now well known that milk contains a heterogeneous mixture of proteins and consequently a variety of methods have been used to separate and characterize the various milk protein fractions since acid precipitation of casein was introduced at the beginning of the 19th century Isolation and characterization of milk proteins is complicated by their considerable tendency to associate and form complexes which makes the definition of their specific physiological, nutritional and immunological characteristics difficult

As the dairy industry in the industrialized world is based mainly on bovine milk, in this chapter I shall concentrate the discussion on cow's milk protein There might of course be interesting aspects when milks from other

species are considered, e g buffalo milk and goat's milk, but the principal problems discussed here are probably also valid for other types of milk

The following questions may be valid when discussing the nutritional aspects of milk proteins

(i) What is the meaning of the nutritive value of a protein?
(ii) From what aspect shall we analyse nutritive value from the global point of view or from the perspectives of industrialized countries, and does it matter?
(iii) What differences exist when we discuss nutritive value with respect to the newborn, infants, adults and elderly persons?
(iv) What is the supplementary effect of milk protein on the nutritive value of dietary protein? It is not valid to discuss only the nutritive value of a single food protein in relation to another as we do not base our diet on a single food item Consequently when discussing the nutritional value we should also take into consideration the supplementary effect of one protein on other proteins in the diet

2. WHAT IS MEANT BY THE NUTRITIVE VALUE OF A PROTEIN?

The nutritive value of dietary protein is essentially related to its amino-acid composition as well as to the availability of these amino-acids In this respect it is well known that milk proteins have a high content of essential amino acids Thus egg and milk proteins are often used as references for the evaluation of the nutritive value of food proteins mainly because they seem to be the only ones originally intended to function as a single source of nutrients for the offspring However, it is obvious that there is quite a difference in the protein and amino-acid composition between egg and milk[11] (Table 2), as well as between milks from various species Consequently it seems most logical to use human milk composition as reference This is the basis of the present FAO/WHO reference amino-acid pattern[13] and will also be used in this chapter

When discussing the nutritive value of a protein we must furthermore consider that the protein requirement can be divided into two categories (1) growth requirement, and (2) maintenance requirement The first refers particularly to the situation in infants and children but also to pregnant and lactating women as well as to adults during convalescence when there is increased protein synthesis The maintenance requirement, on the other

TABLE 2

ESSENTIAL AMINO-ACID CONTENT IN SKIM MILK POWDER, WHEY PROTEINS AND CASEIN, AND AMINO-ACID PATTERN IN FAO EGG REFERENCE (1965) AND FAO PROVISIONAL AMINO-ACID SCORING PATTERN (1973)[a]

Amino-acid	*Skim milk powder*	*Casein*	*Whey protein*	*Human milk*		*FAO egg reference pattern 1965*	*FAO provisional amino-acid Scoring Pattern 1973*
Reference	11	11	14	11	15	12	13
Isoleucine	52	54	76	40	49	66	40
Leucine	97	95	118	86	91	88	70
Lysine	71	81	113	67	65	64	55
Methionine + cysteine	34	32	52	29	37	55	35
Phenylalanine + tyrosine	96	111	70	66	76	100	60
Threonine	41	47	84	44	44	51	40
Tryptophan	14	16	24	NA[b]	NA[b]	16	10
Valine	63	75	72	45	52	73	50
Total essential amino-acids	468	511	609			513	360

[a] The values refer to mg amino-acid per g protein

[b] NA, not analysed

hand, refers to the need to cover the daily turnover of about 400 g of body protein of which about 25% comes from the diet

It is still a somewhat open question whether there is a qualitative difference with regard to the need for essential amino-acids to meet these two requirements It appears that with humans, even for growth, the need for essential amino-acids in general is not as high as the percentage in egg protein[13] However, there seems to be a close connection between the amino-acid pattern of cow's milk expressed as mg amino-acid per g protein, and the amino-acid requirement of infants based on various nitrogen balance studies[16,17] The amino-acid requirements fall sharply with age, as does protein requirement, which at 18 months of age is considered to be only about 50% of that of the newborn Consequently in evaluating nutritive value, amino-acid scoring or the use of human milk protein as reference, will underestimate the nutritional value or quality of food proteins for adults This also means that the superiority of milk proteins to

others, e g vegetable proteins, from the nutritive viewpoint is less valid when diets for adults are considered

There is however a further aspect to the nutritive value of a protein the occurrence of any specific physiological property of a protein which might have a nutritional implication Such examples are the iron-binding lactoferrin[18] and the specific vitamin B_{12}-binding protein which occur in substantial amounts in human milk [19,20] It is quite obvious that such a specific property will be difficult to obtain from other dietary protein sources, whether they are of vegetable or animal origin

3. HOW DO WE ESTIMATE NUTRITIONAL VALUE?

Assessment of the nutritive value of food proteins comprises several types of analyses (Table 3)

3.1. Biochemical Evaluations

Biochemical analysis comprises assay of the nitrogen content, usually by the Kjeldahl method, as well as determination of the amino acid composition after acid hydrolysis or enzymatic digestion *in vitro* of the proteins

In food tables, the protein content of various food items is almost always based on indirect calculations derived from nitrogen analyses The nitrogen value derived from the analysis is multiplied by a conversion factor, usually 6 25, as most proteins have a nitrogen content of 16 % However, it is quite obvious that the nitrogen contents of various amino-acids differ (Table 4) Consequently the conversion factor is substantially dependent on the amino-acid composition of the protein and various factors have been used for different proteins,[11] as illustrated in Table 5 However, in the interest of standardization, the protein content is usually expressed as 'crude protein' which refers to the protein content derived using 6 25 as conversion factor

Nutritionally, the protein content and composition of milk must be analysed from two aspects firstly, the various protein components of the protein moiety *per se* must be analysed from the physiological and immunological viewpoints, and secondly, the proteins must be considered as a source of amino-acids for protein synthesis by the newborn

The protein composition as well as the individual proteins have been far more extensively studied in bovine than in human milk [8] In addition to various more or less milk specific proteins, such as the caseins and the whey proteins, milk also contains a significant amount of non-protein nitrogen

TABLE 3

METHODS FOR EVALUATION OF NUTRITIVE VALUE OF PROTEIN

In vitro methods
- Biochemical methods
  - Nitrogen analysis
  - Amino-acid analysis
- Microbiological methods
  - Amino-acid analysis
  - Digestion by proteolytic micro-organisms
    - *Streptococcus zymogenes*
    - *Tetrahymena pyriformis*
- Enzymatical methods
  - Enzyme preparations
  - Proteolytic micro-organisms

In vivo methods
- Biological tests with experimental animals
  - Screening methods (*ex* PER)
  - Nitrogen balance studies (NPU, BV, NDpCal%)
  - Indirect nitrogen analysis
  - Toxicological studies
- Human tests (in adults and infants)
  - Acceptability tests
  - Nitrogen balance studies

TABLE 4

NITROGEN CONTENT IN AMINO-ACIDS (%)

Less than 16 0%		*More than 16 0%*	
Tyrosine	7 7	Asparagine	18 7
Phenylalanine	8 5	Glycine	18 7
Methionine	9 4	Glutamine	19 2
Glutamic acid	9 5	Lysine	19 2
Aspartic acid	10 5	Histidine	27 1
Hydroxyproline	10 7	Arginine	32 2
Isoleucine	10 7		
Leucine	10 7		
Cystine	11 7		
Threonine	11 8		
Valine	12 0		
Proline	12 2		
Serine	13 3		
Tryptophan	13 7		
Alanine	15 7		

TABLE 5
NITROGEN-PROTEIN CONVERSION FACTORS[11]

Wheat (whole grain)	5 83
Maize	6 25
Rice	5 95
Potato	6 25
Bean	6 25
Soybean	5 71
Sunflower	5 30
Beef	6 25
Egg	6 25
Cow's milk	6 38
Human milk	6 38[a]

[a] If corrected for non protein nitrogen content based on data from Lonnerdal *et al* [15] the conversion factor would be 5 18

which includes urea, creatine, creatinine, α-amino nitrogen compounds, some free amino-acids and other substances [21]

Interestingly, human milk and cow's milk contain almost the same amount of non-protein nitrogen (40–50 mg per 100 ml), however the total amount of nitrogen is much lower in the former, being only about 200 mg per 100 ml versus 540 mg per 100 ml in cow's milk The protein content of human milk calculated on the basis of total nitrogen determinations using the same conversion factor as in dairy chemistry, 6 38, has been reported as 1 1–1 2 g per 100 ml [11 22] However, in cow's milk only 5% of the nitrogen occurs as non-protein nitrogen while as much as 25% of the nitrogen is derived from non-protein nitrogen in human milk The value of 'crude protein' consequently represents an overestimation by about 20% Recent investigations based on analysis of total nitrogen minus non-protein nitrogen, as well as calculations on the basis of amino-acid analysis of true proteins, have shown the true protein content in human milk to be only 0 8–0 9 g per 100 ml in milk obtained from well-nourished as well as from malnourished mothers [15 23 24] Such a low protein content in human milk was reported as early as 1931 [25] A protein determination based only on nitrogen analysis might consequently be misleading when the nutritive value is analysed

Human milk thus seems to have the lowest protein content of all milks

and the protein fraction comprises only about 7% energy of the milk. However, not only is the protein content of human milk much lower than that of bovine milk, the protein composition is also quite different as the whey proteins constitute 70–80% of the total protein in human milk whereas the caseins dominate in bovine milk, representing about 80% of the total protein.[1,24]

With respect to amino-acid analysis, which is usually performed by ion exchange chromatographic methods using amino-acid analysers, the results must be evaluated carefully. This analysis does not differentiate between amino-acids bound in proteins and those which appear free. Furthermore, some amino-acids are destroyed during analysis, i.e. tryptophan, or may react to form unavailable components, i.e. lysine, due to Maillard reactions during food preparation.

The amino-acid content of a food protein is often expressed in relation to that of a reference protein, using the term 'chemical score', which was first introduced by Block and Mitchell.[26] The amino-acid which occurs in the lowest concentration in relation to the amount in the reference protein is called 'first limiting amino-acid', and the percentage represents 'chemical score' or 'amino-acid score'. However, one serious limitation of all amino-acid reference patterns used to date is the fact that the sulphur amino-acids, methionine and cysteine/cystine, are added together, as are the aromatic amino-acids, phenylalanine and tyrosine. This has some nutritional implications, especially when dietary proteins for use during early infancy are evaluated as nutritive sources. Another disadvantage is the fact that the score value is influenced only by the content of the limiting amino-acid and gives no information regarding changes in any of the other essential amino-acids as long as there is no change in the first limiting amino-acid. Thus any destruction of lysine in milk products as a result of the Maillard reaction will result in no change in the chemical score value of the milk product until lysine has become the first limiting amino-acid. Nevertheless, the possible role of milk protein as a source of essential amino-acids and supplement for inferior proteins could have changed markedly. Finally, the usefulness of amino-acid score as an index of the nutritive value of a protein is of course completely dependent on the selection of the correct reference protein. This is illustrated in Table 2, where the egg protein reference pattern recommended by FAO in 1965 and the provisional amino-acid scoring pattern recommended by FAO in 1973 are shown in relation to the essential amino-acid content in casein and skim milk. It indicates that, with the egg protein pattern as reference, the sulphur amino-acids are the limiting ones, giving chemical score values of 62 and 58 respectively, while with the FAO

provisional reference pattern of 1973, the chemical scores are 97 and 91 respectively. Consequently a change in the reference pattern has an impact on the nutritional evaluation of food proteins. So far, only scores based on lysine, total sulphur-containing amino-acids and tryptophan have been checked against biological tests of protein quality as these amino-acids are most commonly found as limiting amino-acids in human food.

3.2. Biological Evaluation

Consequently, the biochemical analyses must be completed by some biological methods in order to elucidate whether the amino-acids analysed are available for digestion and absorption in the gastrointestinal tract. For this purpose various biological methods have been used (Table 3), including enzymatic digestion *in vitro* and microbiological determinations using *Streptococcus zymogenes* or *Tetrahymena pyriformis*. However, most methods of assessing protein quality are based upon some type of feeding study with growing laboratory rats. As we are usually interested in the nutritive value of proteins for human consumption it should always be remembered that each species has its own requirements for protein and amino-acids. The final proof of the nutritional value of a protein in the human diet can consequently only be based on metabolic studies in humans. This is, for obvious reasons, not possible to perform to any large extent. Thus, from the qualitative point of view also, analyses of the nutritive value of proteins must to a substantial extent be based on indirect evidence. The concept of the existence of a perfect method for protein quality evaluation is undoubtedly false and there is no possibility of its development.

4. MILK PROTEIN COMPOSITION

Not only are there substantial differences with regard to protein content and composition when milks from various species are compared, but milk also contains a very heterogeneous mixture of proteins.

Milk proteins are often subdivided into two major groups: the caseins and the whey proteins. This separation is based on the fact that casein is precipitated in the dairy industry during cheese manufacture, which leaves whey as a by-product. Maximum precipitation of bovine casein is obtained at pH 4.6 and this is also the most commonly used definition of casein. However, the conditions for maximum precipitation of casein vary for milks from different species, pH 4.0 being optimal for casein precipitation from rat milk[27] while human casein is far more difficult to precipitate.[28]

Temperature and degree of dilution are other factors that influence maximum precipitation of casein It should also be stressed that there is often co-precipitation of whey proteins or non-casein proteins with the caseins In the manufacture of some cheeses this is considered especially desirable in order to get optimal protein recovery from the milk

4.1. The Caseins

As casein is the dominant protein in bovine milk it is of interest to comment on this first It is a very milk-specific protein which occurs in both human and bovine milks,[5] casein represents about 80 % of the protein in cow's milk but only between 20 and 40 % of that in human milk Casein was originally thought to be the sole milk-specific protein, but it is now known to be only one of several [29] It has some inter-species similarities which may have nutritional implications it has a high content of ester-bound phosphate, a high proline content, a low content of sulphur amino-acids, especially of cystine, and low solubility at pH 4–5

The caseins have a unique molecular structure, they occur in micelles containing calcium and inorganic phosphate and represent some of the few naturally-occurring phosphoproteins Mellander,[30] by means of Tiselius free boundary electrophoresis, separated casein in three fractions which he called α-, β- and γ-casein according to their mobility Modern biochemical methods have made it possible to fractionate the caseins further and have also revealed that γ-casein is a degradation product of β-casein [29]

The dominating α_s-caseins are phosphoproteins which precipitate at low concentrations of calcium in the absence of κ-casein Apparently α_{s1}-caseins occur only in milk from ruminants The β-caseins, which also are phosphoproteins, can be distinguished from other casein fractions as their association and solubility in the presence of calcium are temperature-dependent β-Casein seems to be the dominant form in human casein γ-Casein represents the *C*-terminal part of β-casein from which the acidic phosphopeptide of β-casein is missing, γ-casein is consequently no longer referred to as a distinct casein group κ-Casein is unique in several respects and has been shown to occur in milks from cow, goat, sheep and human Firstly, it remains soluble in calcium solution under conditions that precipitate all other casein components κ-Casein can thus occur as a component of the whey protein fraction Secondly, it stabilizes other caseins in the presence of calcium and consequently κ-casein plays a key role in the formation of calcium-containing casein micelles Thirdly, chymosin and several other proteinases specifically hydrolyse a special peptide bond in κ-casein which results in curd formation in the presence of

Ca^{2+} Finally, κ-casein is the only major casein which has carbohydrate side chains

Most of our knowledge regarding the caseins refers to bovine casein There is still limited information regarding inter-species differences with respect to various kinds of casein and little comparative work has so far been done Interestingly, human milk casein seems to comprise predominantly β-casein while α_{s1}-casein is the dominant casein in bovine milk [5] This means that although the total phosphoprotein content of human milk is only about one-seventh of that in bovine milk, the β-casein content represents about half of that in cow's milk. This is of special interest as the amino-acid composition of human β-casein with respect to methionine and phenylalanine differs somewhat from that in cow's milk

It has been suggested that the primary function of the caseins is the nutrition of the newborn This is not only due to their role as a source of amino-acids but also to their role as sources of calcium and inorganic phosphate Calcium phosphate-containing casein micelles make the content of calcium and inorganic phosphate in milk far higher than would be expected from their physicochemical solubility in milk Curd formation may also be of physiological interest for the function of the digestive tract and to enable the gastric enzymes to start protein digestion in the newborn but such functions are difficult to evaluate There are however physicochemical differences between human and bovine caseins resulting in different curd formation characteristics in the stomach The casein micelles of human milk are smaller than those of bovine milk Casein is highly heat-resistant but is precipitated at low pH resulting in curd formation, it is also precipitated by a special enzyme, chymosin, which occurs in the stomach The coagulum from human milk is soft and flocculent whilst bovine milk coagulum is resistant and firmer, the physiological significance of which is still unknown Human casein has a lower phosphorus content than bovine casein but is richer in amino-sugars, sialic acid and reducing non-amino-sugars

The physiological role of casein in the human diet is still not very well known It is consequently somewhat difficult to analyse whether it can be substituted for nutritionally by other dietary proteins Being a very specific phosphoprotein casein probably plays a role in the phosphorus balance in adults also From the nutritional point of view this means that the caseins not only function as a protein source but also as a source of calcium and phosphorus A milk free diet will consequently also have an impact on the calcium intake of a population in all ages for example, in Sweden, 75% of the calcium intake in the national diet comes from dairy products

It is still difficult to evaluate the physiological implication of the proportion of casein relative to other protein components, i e the non-casein proteins or whey proteins, or to other milk constituents, in relation to the nutritional requirements of man As illustrated in Table 1, the casein content differs markedly in relation to that of whey proteins when milks from various mammals are compared, human milk being one extreme with a remarkably low casein content, and milk from the ruminants (cow, buffalo, sheep and goat) representing the other extreme [1] Caseins constitute about 40 % of the protein in human milk whilst the whey proteins constitute the remaining 60 % However, recent analyses in our laboratory[31] show that the casein in human milk might even be as low as 20 % This discrepancy might be due to the fact that a valid method for the quantitative estimation of casein is still lacking and casein is usually determined as the protein fraction that precipitates at pH 4 6 Our findings indicate that earlier values of 40 % are due to the co-precipitation of other milk protein fractions Thus, if the nitrogen contents of the various whey protein fractions, i e α-lactalbumin, lactoferrin, lysozyme, serum albumin and the immunoglobulins (IgA, IgM, IgG), which are determined by specific methods, are subtracted from the total nitrogen content there is only about 20 % left to be constituted by casein in human milk [31]

From the nutritional point of view it is also of interest to comment on the uniqueness of the amino-acid composition of the caseins This is illustrated in Table 6 It is seen that the very low cystine content of the caseins results in a methionine/cystine ratio that is 2–3 times higher than that in other animal proteins and more than seven times that in human milk Human milk in fact seems to be the only animal protein source that has a methionine/cystine ratio below or close to 1 0 This is probably due to its high content of whey proteins and concomitant low casein content This is of considerable physiological interest as it is known that the premature infant lacks the enzymatic capacity to convert methionine to cysteine which makes cysteine or cystine an essential amino-acid [32] The lack of cystine in casein is therefore a nutritional disadvantage Interestingly, the cystine content of milk is almost exclusively derived from β-lactoglobulin and α-lactalbumin The use of casein rich infant formulae is therefore worth further consideration from the nutritional and metabolic point of view [33]

Other remarkable characteristics of the amino-acid pattern of casein are the high contents of proline and arginine which are about twice those of the whey proteins and the low contents of isoleucine, leucine, lysine and threonine, some of them being almost only half of the contents in the whey proteins (Table 6)

TABLE 6

AMINO-ACID CONTENT IN CASEIN AND WHEY PROTEIN

(mg *amino-acid per g total nitrogen*)

	Human breast milk[15]	*Casein*[11]	*Whey protein*[14]	*Egg*[11]	*Beef*[11]	*Wheat (whole grain)*[11]	*Soybean*[11]
Isoleucine	254	345	476	393	301	204	284
Leucine	471	607	736	551	507	417	486
Lysine	337	518	704	436	556	179	399
Methionine	78	178	151	210	169	94	79
Cystine	114	23	174	152	80	159	83
Phenylalanine	171	334	224	358	275	282	309
Tyrosine	223	371	214	260	225	187	196
Threonine	228	297	527	320	287	183	241
Tryptophan		103	147	93	70	68	80
Valine	296	430	449	428	313	276	300
Arginine	171	239	175	381	395	288	452
Histidine	114	186	144	151	213	163	158
Alanine	166	196	341	370	365	226	266
Aspartic acid	451	455	766	601	562	308	731
Glutamic acid	1 000	1 406	1 231	796	955	1 866	1 169
Glycine	98	126	126	207	304	245	261
Proline	513	738	450	260	236	621	343
Serine	228	385	374	478	252	287	320

The contents of the aromatic amino-acids phenylalanine and tyrosine are relatively low in the whey proteins As the newborn infant has a limited capacity to metabolize these amino-acids[34] this seems to be of physiological interest

Casein has been used as reference protein for many years in the evaluation of the nutritive value of proteins, i e determination of PER, NPU and BV It is, however, well known that casein by no means is the optimum protein from the nutritional point of view since several animal proteins, i e egg protein, whey proteins, as well as a few vegetable proteins, i e soy protein, rapeseed proteins, show a higher nutritive value [11] As the sulphur-containing amino-acids are the limiting ones, casein is sometimes supplemented with methionine when used as reference protein It is thus somewhat difficult to accept that the major and only role of the caseins in milk is a nutritional one Further studies are needed to evaluate the physiological implications of the caseins and the reason for the observed differences in casein composition and the casein/whey protein ratio when milks from various mammals are compared

4.2. Whey Proteins

Whey is a highly nutritious by-product of cheese and casein manufacture which contains about 0 6% protein The whey proteins represent the non-casein proteins as well as the fractions and fragments of the caseins which remain soluble when the caseins have been precipitated enzymatically by rennet or isoelectrically by acid They represent an even more heterogeneous protein mixture than the caseins and share very few common characteristics except that of being soluble under conditions that precipitate the caseins Milks from carnivorous mammals contain a considerable amount of milk-specific non-casein proteins, while milks from other species, especially rodents, contain very little Some of the whey proteins seem to have distinct physiological and biochemical roles, e g lactoferrin strongly binds iron, α-lactalbumin is a constituent of lactose synthetase and lysozyme is an enzyme that destroys the bacterial cell wall With respect to β-lactoglobulin, which is the dominant whey protein in bovine milk, we still lack information regarding any specific physiological role

If we want to compare the specific nutritive value of milk protein for humans with that of other proteins it is of interest to analyse the points of resemblance and differences in the protein composition of cow's milk and that of human milk As shown in Tables 1 and 7 there are two major differences (i) there is an almost inverse relationship between casein and the whey proteins, and (ii) there are obvious differences in the composition of the whey proteins Unfortunately we still do not fully understand the

TABLE 7
WHEY PROTEIN COMPOSITION IN HUMAN MILK AND COW S MILK
(mg *protein*/ml)

Protein	*Human milk*	*Cow s milk*
α Lactalbumin	1 6	0 9
β Lactoglobulin	—	3 0
Lactoferrin	1 7	0 012
Lysozyme	0 4	0 000 1
Serum albumin	0 4	0 3
Immunoglobulins		
IgA	1 4	0 03
IgG	0 01	0 6
IgM	0 01	0 03

Source Hambraeus and Lonnerdal unpublished observations

physiological implications, either nutritionally or metabolically, of these differences

4 2 1 *β-Lactoglobulin*

β-Lactoglobulin is the dominant whey protein in bovine milk It is relatively heat labile It occurs in the milks of all ruminants and homologues of β-lactoglobulins have been isolated from the milks of cow, goat, water buffalo and sheep Although it has been reported to be absent from human milk[35] as well as from the milks of the camel and guinea pig, Liberatori *et al* [36] recently reported that β-lactoglobulin occurs in minor amounts in human milk The physiological function of β-lactoglobulin has not yet been established There has, however, been some speculation that it plays a regulatory role in phosphorus metabolism in the mammary gland [37] Some of the changes in the properties of milk that take place on heating are due to denaturation and aggregation of denatured β-lactoglobulin with other proteins such as the formation of a disulphide bond between β lactoglobulin and κ-casein It has been postulated that β-lactoglobulin may be the factor responsible for the increased incidence of milk allergy in infants fed formulae at an early age where the whey protein/casein ratio is 60/40

4 2 2 *α-Lactalbumin*

α-Lactalbumin is one of the three dominant protein components in human milk and the second most dominant protein among the bovine whey proteins It has a stable configuration between pH 5 4 and 9 and it is also the most heat-stable whey protein It occurs in the milks of all mammals although it is present at very low levels in milks containing little or no lactose, i e milk from the northern fur seal and the sealion α-Lactalbumin is part of the enzyme lactose synthetase[38] and the biosynthesis of lactose seems to be regulated by the production of α-lactalbumin Consequently there seems to be a relationship between the content of lactose and that of α-lactalbumin when milks obtained from various mammals are compared There is however no direct correlation between the lactose and α-lactalbumin contents of human milk according to transversal and longitudinal studies [15 39] which showed that the lactose concentration increases whilst α-lactalbumin content decreases throughout lactation Although the primary role of α lactalbumin seems to be its enzymatic function it is obvious that it also plays a significant nutritional role as it has a very high nutritive value This might explain why the content of α-lactalbumin is so high in human milk The complete amino-acid sequences of α-lactalbumin

of bovine and human milks are known and its amino-acid composition seems in many respects to be optimal for the requirements of the human baby

4 2 3 Iron-binding Proteins

Milk contains two kinds of iron-binding proteins, transferrin, which seems to be almost identical to the transferrin in blood, and lactoferrin, which is closely related to transferrin but characteristic for milk Lactoferrin was earlier called 'red protein' and is synthesized in the mammary gland, but it is also secreted in saliva, tears and semen [40] Lactoferrin, together with α-lactalbumin, are the principal whey proteins in human milk [15 39 41] It has also been identified but at much lower concentrations in milks from cow, goat, horse, pig, mouse and guinea-pig It seems, however, to be absent from rabbit milk, where transferrin is one of the principal whey proteins, as well as from milks from rat and dog All mammals, however, seem to be able to produce these two iron-binding proteins although they do not occur to the same extent in all milks

Lactoferrin, like transferrin, is a glycoprotein and binds two ferric ions with incorporation of two molecules of bicarbonate However, neither lactoferrin nor transferrin is fully saturated with iron Transferrin is known to act as a carrier for iron within the body, and it is suggested that lactoferrin plays a similar role for the absorption of iron in the gut of the suckling Whether this is so also where lactoferrin is a major whey protein component, as in human milk, has still to be elucidated It should, however, be remembered that iron from breast milk is absorbed to a much higher degree (50–75 %) than iron in infant formulae based on cow's milk [42] The low protein, low phosphorus and high lactose contents of human milk have been assumed to favour the bioavailability of iron This might be one reason why breast-fed infants do not show signs of iron deficiency during the first 4–6 months although the iron content of breast-milk is low, 0 3–0 5 μM per ml Lactoferrin is also considered to play an essential role in the resistance against intestinal infections caused by *Escherichia coli* [43] Since bacteria require iron for growth, lactoferrin, which occurs in a highly unsaturated form in human milk, only 2–4 % of its iron-binding capacity being saturated,[44] probably binds iron so strongly that it makes it unavailable for the bacteria Saturation of lactoferrin has on the other hand been found to reverse its bacteriostatic effect in nature [45] Interestingly only a minor fraction of the iron in human milk is really bound to lactoferrin under normal conditions, whilst about one-third is bound to the fat fraction and another one third to some low-molecular components [44] It is

of interest in this respect to note the observation by Lonnerdal *et al*[41] of the increased lactoferrin content of human milk obtained from Ethiopian mothers who have a very high dietary intake of iron Consequently, the nutritional significance of the low lactoferrin content of bovine milk, when this is used in infant formulae, needs further elucidation[46]

4 2 4 Immunoglobulins

Milk contains a number of immunoglobulins which represent a very heterogeneous group of proteins Immunoglobulin, IgA, seems to be most specific for milk and occurs primarily in colostrum and mature milk of certain species, i e human milk and milks from primates In ruminants IgA is a minor component and the less milk-specific immunoglobulins IgG and to some extent also IgM dominate Immunoglobulin A mainly occurs as secretory IgA, which is composed of two molecules of IgA covalently bound together with the two polypeptides, the 'secretory piece' and the 'junction chain' The secretory piece was earlier described as glycoprotein A when it was first isolated from bovine milk Secretory IgA is very stable at low pH and also comparatively resistant to proteolytic enzymes It seems to play an essential role in the defence of the intestinal mucosa against invasion by viruses and bacteria

4.3. Miscellaneous Milk Proteins

So far the major protein components of milk have been discussed There are also, however, various minor components such as B_{12}-binding protein, which has been shown to compete with B_{12}-removing micro-organisms[19 20] Lactollin was isolated from bovine milk by Groves,[47] but its function is still unknown Ceruloplasmin, a copper-binding protein, has been shown to occur in colostrum and mature milk as well as the serum of cattle Various glycoproteins and a number of protein constituents of the fat globule membrane have also been described Interestingly, many enzymes have been reported in milk Lysozyme represents a milk protein which occurs in remarkably high concentrations in human milk compared with milks from other species[48] It has a direct bactericidal effect since it is capable of degrading the bacterial cell wall and enhancing the activity of the immune antibodies Not less than 44 different enzymes, which have been detected in bovine, human and some other milks, were listed in a recent survey by Jenness[1] The physiological and nutritional significance of several of these enzymes in milk is still not understood

5. MILK PROTEINS IN THE HUMAN DIET

I have given a short review of the various milk proteins and their specific characteristics with special reference to the nutritional aspects. As human milk is used as reference protein for the estimation of the nutritive value of proteins it is not too surprising to find that milk protein has a high nutritive value. The role of milk proteins in the human diet for infants as well as for adults may be of even greater interest as, in practice, milk is usually consumed in the national diet as one of the staple foods. We do not consume one protein source alone but a mixed diet based on several food proteins. Obviously milk has been consumed by humans since early history and the use of domestic animals is known from Babylonia and Egypt. The use of dairy products, e.g. milk and cheese, is also mentioned in the earliest parts of the Bible.

5.1. Supplementary Effect of Milk Proteins

As illustrated in Table 2, the amount of essential amino-acids in milk protein is close to what is expected to be the optimal amino-acid requirement and composition for the human being. Consequently the best application of milk proteins seems to be as a supplement to cheaper vegetable proteins, thus taking advantage of its abundance of essential amino-acids which enhance the nutritive value of a mixed diet, as it nutritionally supplements inferior proteins (Table 6). This enhancing effect is most obvious when small amounts of milk are used to supplement cereals. This is also of great international importance with respect to global food scarcity as by far the larger part of the world's population relies on cereals as their staple food.

As stated above, the most realistic and practical approach to discussing the role of milk proteins is to divide them into the two groups in which they usually occur in the human diet: the casein and the whey proteins, and in addition to comment on the role of total milk proteins in the human diet. It is well known that milk products play an essential role in the human diet in several countries. Of special interest is the fact that due to their high nutritional value they can supplement the diet to a significant extent even if they represent only about 10% of the total protein intake. Another important factor is that milk products are usually consumed by those who are in special need for a nutritionally well-balanced diet, i.e. the vulnerable groups comprising infants and pre-school children. The various milk products, i.e. fresh milk, fermented products (yoghurt and sour milk), as

well as cheese, all represent very valuable supplements in the human diet Cheese manufacture also represents a method of preserving the nutritionally high-value proteins of milk, which itself cannot be stored readily

In this aspect of supplementation, it is once more of interest to discuss the nutritive value of the various protein fractions in milk During recent years special interest has been devoted to the utilization of whey proteins in the human diet [49, 50] Most probably, one important function of the whey proteins is their contribution to the nutritive value of milk protein Thus the nutritive value of casein, which does not seem to be optimal from the human point of view, is inferior to that of the whey proteins It has also been postulated that casein is counterbalanced by whey proteins in human milk in order to balance the supply of essential amino-acids to the newborn

The high nutritive value of the whey proteins is mainly due to their high content of essential amino-acids [49] This is illustrated in Fig 1, which shows

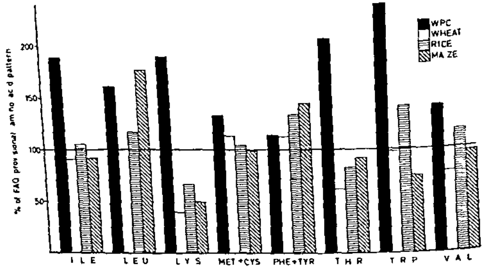

FIG 1 Essential amino acid contents of a whey protein concentrate (WPC), wheat, corn and rice expressed as a percentage of the FAO provisional amino acid reference pattern of 1973 [51]

the essential amino-acid content of whey protein concentrate, WPC, as well as of some cereal proteins (wheat, maize and rice) expressed as a percentage of the FAO reference pattern [51] It is seen that whey protein concentrate has a surplus of all essential amino-acids compared with the FAO pattern Of special interest are the high contents of isoleucine, lysine, threonine and

tryptophan Wheat is low in lysine and threonine, while maize is low in lysine and tryptophan Rice, on the other hand, has a relatively well-balanced amino-acid composition although the contents of lysine and threonine are fairly low

So far the whey proteins have not been used to any great extent in the human diet although they have a remarkably high nutritive value, when they are used it is mainly for their functional properties in beverages, ice cream and so on Most of the whey proteins are still used in animal feed as the production of whey still represents a serious pollution problem for most dairy industries The US so far seems to be the country where whey proteins are used to the largest extent in the human diet 68% of dry whey production is said to be used in the human diet compared with 17% in the rest of the world One special issue is their use in infant formulae This has been developed as it is known that human milk contains a substantial amount of whey protein Although infant formulae might show the same ratio of whey proteins to casein as in human milk there are still significant qualitative differences since the whey protein composition differs markedly in bovine and human milk This is illustrated in Fig 2, which shows the protein composition of bovine milk, human milk and the so-called humanized infant formula or adapted formula The nutritional significance of these differences is still not known [52] It should, however, be remembered that the low lactoferrin and lysozyme contents of the formula might have an implication for the iron status of the infant as well as for resistance against intestinal infections The high content of β-lactoglobulin of bovine milk might have a significant implication for the observed cow's milk allergy in infancy since β-lactoglobulin is a foreign substance for the human as it is absent in human milk Consequently there is still a need to study further the optimal use of milk protein in the human diet

One of the characteristics of the amino-acid pattern of whey proteins, as well as of breast milk, is the relatively low content of the aromatic amino-acids, phenylalanine and tyrosine This makes them suitable as a protein source in the dietetic treatment of patients with a disturbed metabolic capacity for these amino-acids, i e phenylketonuria, tyrosinaemia and hyperphenylalaninaemia This has also been confirmed in studies on the effect of a formula in which whey protein concentrate constituted the sole protein source for an infant with hyperphenylalaninaemia It was then possible to obtain a more positive nitrogen balance and a more pronounced nitrogen retention than with a conventional humanized infant formula, which furthermore illustrates the high nutritional value of the whey proteins [53] The use of whey protein formulae in clinical dietetics was also

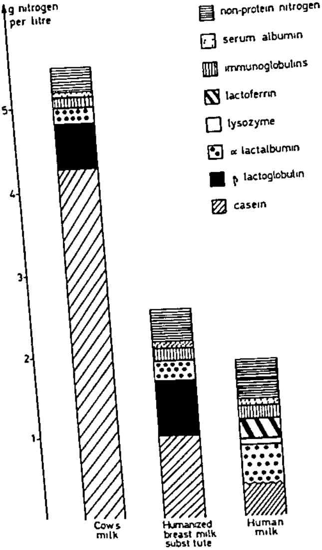

FIG 2 Protein composition of cow s milk, humanized milk formula and human milk Nitrogen derived from the various proteins and non protein nitrogen are given as g N per litre (from Hambraeus *et al* [52])

proposed for adults[54] and might indicate a new trend for better utilization of the high biological value of the whey proteins

In the future it might be possible to use single and specific protein fractions to an increased extent for nutritional and pharmacological purposes This might be one of the most economic ways to utilize the whey proteins, which today still represent a problem for the dairy industry, and at the same time take advantage of their specific characteristics

6. CONCLUSION

Milk certainly represents one of the most complete single foods and the different composition of milks from various species might be an indication by Nature of the specific nutrient requirements of that species The use of various milks in the human diet without doubt takes advantage of their content of essential nutrients and milk products function as high-value supplements to many diets in different regions of the world There are however, still many problems to be solved regarding the physiological implication of the various characteristics of the protein constituents of milks and its relation to the nutritional requirements of the offspring More studies are required and it is possible that various specific milk protein components could be used in the future for specific nutritional and pharmacological purposes

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Chapter 10

MANUFACTURE OF CASEIN, CASEINATES AND CO-PRECIPITATES

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1. INTRODUCTION

Casein, which is the main protein of milk, may be obtained by acidifying skim milk to a pH of about 4 6 Indeed, casein is defined as the protein precipitated at this pH at 20 °C [1] The relative simplicity of its isolation and its useful properties as an adhesive or a food ingredient have led to the manufacture of casein during most of the 20th century [2 3] From small-scale production of casein in the early 1900s for use in glues,[2] the industrial applications expanded, particularly for papercoating World production of casein doubled between the mid-1930s and the mid-1960s, when it reached about 150 000 tonnes,[3] a level from which there has been little change in recent years [2] The major change has been in the end-uses of casein From the early 1960s there has been rapid development of food applications for casein and a decline in the industrial uses Today, between 70 and 80 % of world production is for food ingredients [2 4] The introduction of more efficient methods of manufacture in plants designed to make an edible-quality product elevated the status of casein for both industrial and food applications [3] The increasing sophistication of end-user requirements for industrial casein, even higher for edible grades, raised the pressure on manufacturers to produce improved milk protein products with specific functional properties and closely controlled quality [5] These changes led not only to improvements in the quality of casein, but also to the development of a range of caseinates and of co-precipitates of casein and whey proteins

These developments have been described and the manufacturing methods outlined in several reviews and texts [2 3 6,7]

2. ACID CASEIN

The essential steps in the manufacture of acid casein are the efficient separation of whole milk to produce skim milk with a minimum milk-fat content, precipitation of the curd by reducing the pH to about 4.6, adjustment of temperature to aid the expulsion of whey (syneresis) and so produce a curd of optimum firmness for separation from the whey, washing, pressing or centrifuging for de-watering, and then drying and grinding.

The reduction of pH is achieved by the action of lactic acid bacteria (starters) or by the addition of an acid to the skim milk. The term lactic casein is normally used where pH reduction is achieved by the use of starters. Casein precipitated by acid usually includes the name of the acid in its description, e.g. hydrochloric acid casein, sulphuric acid casein or lactic acid casein, but may simply be called acid casein.

2.1. Precipitation and Curd Formation

2.1.1. Lactic Casein

The earlier method for making lactic casein involved carrying out the wet processing stages in a cheese vat.[8] The vats were filled with skim milk at 26–27 °C, and this was then inoculated with 0.5–1.5% of a mixed starter, usually consisting of strains of *Streptococcus lactis* and/or *S. cremoris*. After about 16 h a coagulum formed, and the temperature was raised by the injection of steam—'cooking'. Cheese knives were sometimes used to cut the curd before cooking so as to promote syneresis as the temperature increased. Syneresis was further assisted by gentle agitation of the curd during the period of about one hour required to reach the final temperature of up to 60 °C. The curd was then allowed to settle and the whey drained off before washing commenced.

In an effort to reduce the time and labour required in this process, an early approach[9] involved using a steam injector to draw the coagulum from the vat while increasing the temperature to about 58 °C and creating curd particles in a suitable condition for the later stages of processing. In New Zealand it was found that the coagulum could be pumped without detrimental effects on the nature of the curd during syneresis and washing.[10] The cooking temperature was attained by injecting steam while the coagulum was being pumped, a holding pipe or vat being used to allow the curd to agglomerate and so initiate syneresis.

Pumping the coagulum and using steam injection permitted large vats to be used for coagulation. As developed in New Zealand,[11] the system

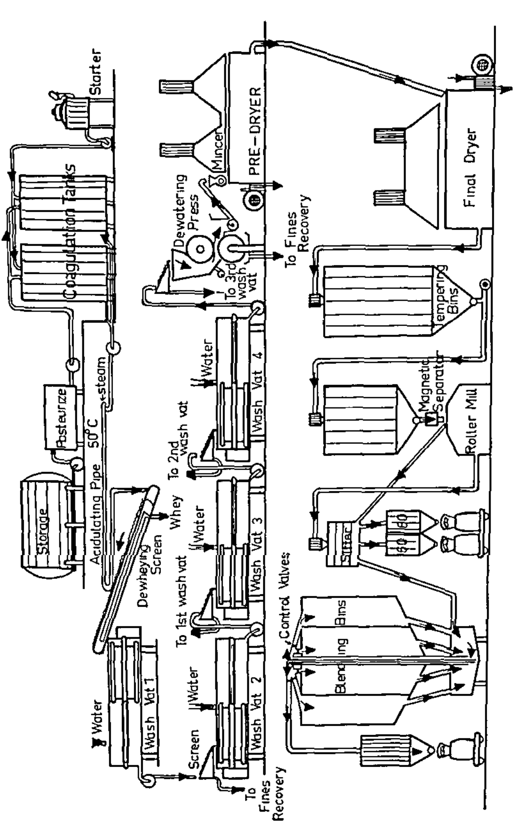

FIG 1 Lactic casein manufacture—New Zealand plant design Reproduced from *Dairy Sci Abstr* by permission of the publishers

normally employed vertical silo tanks of up to 100 000 litres capacity for the coagulation stage, followed by continuous cooking, washing, pressing and drying Figure 1 (from ref 11) illustrates the entire process

This system is still used extensively in New Zealand, where the continuous stages of the process are commonly at the rate of 20 000–50 000 litres of skim milk/h, representing 0 6–1 5 tonne casein/h [2] The process now used for the manufacture of edible-quality lactic casein involves pasteurizing the skim milk and inoculating it with 0 1–0 5% of starter at a temperature of 22–26°C followed by incubation for 14–16 h [2] The precise rate of acid production by the starter is not important as coagulation usually takes place several hours before processing begins, and at the pH of the coagulum—about 4 5—the culture is in the stationary phase of growth [12] However, there can be occasions when the pH of the coagulum is lower than desirable for the formation of a firm curd during cooking In such cases, the addition of skim milk to adjust the pH has been proposed [13] However, a more common problem is slow production of acid due to the action of bacteriophages on the starter organisms Mixed starters, composed largely of *S cremoris*, have been used successfully in New Zealand for many years, probably because of the build-up of bacteriophage resistant strains [14] Endeavours were made to develop a more controlled starter system by using starters with four *S cremoris* isolates for which no 'phages had been encountered [15] Virulent 'phages soon appeared after using this starter in a casein factory but, by the regular addition to the four component strains of bacteriologically filtered whey from the previous day s manufacture, the starter was used successfully for an entire season [15] This technique encourages the growth of bacteriophage-resistant strains In a further development, a multiple starter of 32 isolates of *S cremoris* was found satisfactory when the culture was replaced weekly from deep frozen stocks or when filtered whey from the previous manufacture was added regularly to the mother culture [12] These authors[12] based their work on *S cremoris* since although *S lactis* strains had been found less susceptible to inhibitory substances in milk *S cremoris* was more satisfactory if, during processing of the casein whey, it required clarification [16]

2 1 2 *Acid Casein*

The long period required during lactic fermentation for the pH to be reduced to about 4 6 provides ample time to attain equilibrium conditions in producing casein aggregates virtually free of bound calcium Hence cooking temperatures of 50–55°C are generally needed to create a curd firm

enough for subsequent processing The earlier systems for precipitating casein with acid involved adding acid to batches of skim milk at about 42 °C,[17] or mixing skim milk and acid continuously at 43–45 °C in a baffled chamber followed by discharge into a chute with baffles designed to favour agglomeration of the curd [3] The pH of the mixture was usually about 4 3, thus providing a surplus of acid to help remove calcium in the holding (acidulation) stage that followed This system was found to produce a high proportion of very small casein particles (fines) which tended to be lost in the whey, thus reducing the yield of casein by up to 9 % When a higher pH or a higher cooking temperature was used in an attempt to reduce fines losses, the curd formed into 'rubbery' large aggregates that presented difficulties in further processing and gave a casein of high ash content

It was found[18] that at 43–45 °C the coagulum began to form in less than 0 1 s, too short a time to achieve completion of the reaction between casein micelles and the acid Lowering the temperature at mixing to 30–35 °C and pumping dilute acid through a spray into a turbulent zone in the milk line gave efficient mixing before coagulation began Steam injection was then used to reach a cooking temperature of 44–46 °C This technique reduced losses of fines in whey to 1–2 % of the casein and was widely adopted [3] This system (Fig 2) was designed originally for milk flow rates of up to 10 000 litres/h In recent years, larger flow rates have become common Efficiency tended to be reduced unless the system design was altered appropriately This factor, and variations in the control of pH and temperature, have been observed (ref 4, and by the author) to lead to an increase in fines losses

A further development of the principle of mixing at reduced temperature overcame these difficulties [19] The plant (Fig 3) provided for stabilization of pH by the use of accurate measuring pumps to ensure a constant flow of milk and acid, mixing acid with skim milk at a controlled temperature below 25 °C to ensure attainment of equilibrium conditions before coagulation begins, automatic regulation of steam injection to achieve the coagulation temperature, and the use of a holding tube to obtain complete coagulation and a well-structured curd This approach ensured that losses in whey were less than 1 % of the casein [4]

Hydrochloric acid is most commonly used as a precipitant as it is usually available at a reasonable price and is known to produce a high quality casein [3] Sulphuric acid is also used and it too will result in a high-quality casein if suitable precipitation conditions are used [20] Ion-exchange, to replace cations in deproteinated whey with hydrogen ions, has been applied in reducing the pH to about 1 8 prior to using the treated whey as the

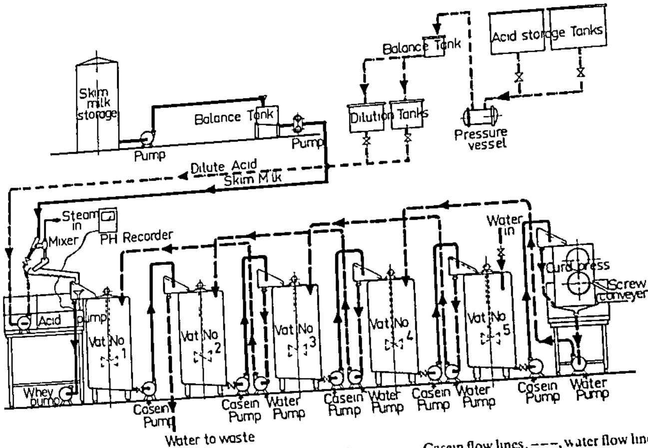

FIG 2 Hydrochloric acid casein manufacture—Australian plant design —— Casein flow lines, ---, water flow lines, - - -, acid flow lines Reproduced from *Dairy Sci Abstr* by permission of the publishers

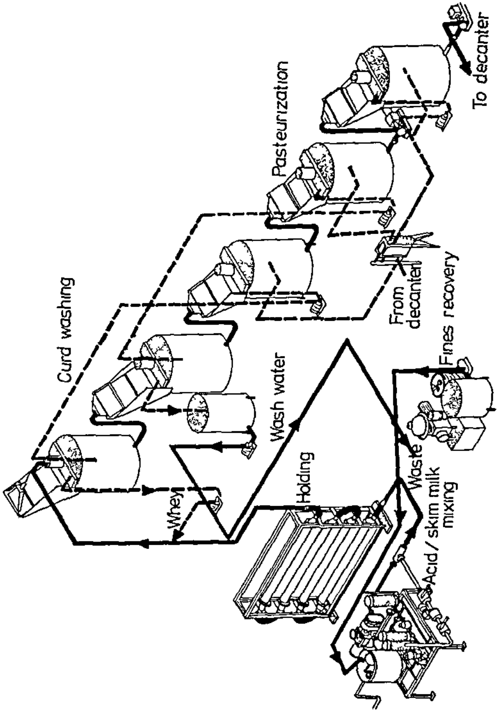

FIG 3 European equipment for low-temperature mixing of acid and skim milk, and curd washing

precipitant for acid casein [21] More recently it has been proposed that ultrafiltration be used to increase the protein content of skim milk to 5–7% and to produce a permeate which is treated by cation-exchange and then used to precipitate the casein [22] These techniques avoid incorporating the anions of hydrochloric or sulphuric acid in the whey resulting from casein manufacture and so aim to increase the value of the whey as a raw material for further processing

2.2. Separation of Curd and Washing

2 2 1 *Whey Removal*

It is well known that production of a casein of high quality requires efficient separation of curd from whey and thorough washing to reduce the content of lactose in the final product [3] It has been shown[23] that the efficiency of a particular casein washing plant can be increased by improving the system for separating whey from the curd or by adding extra washing stages A number of systems have been used for continuous separation of curd from whey A system developed in New Zealand (illustrated in Fig 1) separates the whey on a moving, inclined nylon screen, the most commonly used device The curd is sprayed with water to decrease the amount of whey carried into the first washing stage [11] The screen developed in Australia[24] was of 90-mesh stainless steel gauze inclined at an angle of 60° from the vertical (Fig 2) Comparison of the efficiency of this screen with that of two types of vibrating screen led to a suggestion that the latter type should be considered for curd–whey separation A more efficient inclined screen was developed in Europe [4] This was based on a polyester fabric (80 μm) laid on a cascade like profile which subjects the curd to turning and rolling as it travels down the slope and so increases the efficiency of separation

Studies in New Zealand[25] showed that the efficiency of an inclined screen for separation of curd from whey was a function of the angle, the length of the screen and the aperture size The screen developed for processing rates of about 23 000 litres/h was of 180 μm stainless steel mesh, 0 75 m × 1 20 m and with the facility to adjust the angle in the range 20–45° It has been shown that continuous roller presses can be used for removing whey from curd [26] Provided the temperature and pressing conditions are controlled so as to avoid excessive matting of the curd, the curd moisture content can be reduced to about 65%, compared with about 85% from inclined screens Some 20% more whey is recovered and less wash water is needed Similar considerations have led to the use of horizontal centrifuges for 'de-wheying' [27]

The choice of de wheying system depends not only on the consideration

of capital and operating costs but also on the approach of the particular dairy factory to whey utilization and effluent disposal

2 2 2 Washing and Pressing

The removal of lactose, salts and free acid from casein by thorough washing is an essential feature of the manufacture of a high-quality product These impurities diffuse from the curd during washing and the diffusion rate depends on the size and permeability of the curd particles, and on the purity, amount, temperature and rate of movement of the wash water [28] In continuous washing systems (Figs 1–3), a counter-current flow of water reduces the quantity of water needed to about 50 % of the skim milk flow rate and reduces the loss of fines through the restriction of one outlet At least three washing stages, with water flow rates adjusted to provide an average holding time of about 30 min in each stage, are necessary to reduce lactose to the desired level of about 0 1 % in the dried casein [3]

Where the water used for washing has more than a given level of alkalinity[29] it is often necessary to add acid to maintain a pH of about 4 6 so as to avoid softening and re-dispersion of the curd Sulphuric acid is preferred for the purpose as casein is much less soluble in this acid than in hydrochloric acid The latter may cause formation of a gelatinous layer over the curd particles if the pH is too low Wash waters should be clear, as colour or turbidity will be absorbed by the curd and discolour the product [3]

The temperatures used in washing are chosen so as to maintain the curd in a suitable condition for agitation, pumping as necessary and separation at each stage from the wash water The aspect of bacterial destruction is also given careful attention When the skim milk is pasteurized it is not necessary to exceed greatly the cooking temperature during washing of acid-precipitated casein With lactic casein, higher temperatures are necessary during washing to reduce to low numbers the bacteria which multiply during incubation of the milk with starter [30] However, even with acid-precipitated casein it is normal, as a safeguard against bacterial contamination, to apply temperatures of 70 °C or more at the penultimate washing stage The final washing stage is normally at 40–45 °C to minimize matting of the curd during its separation from wash water by a continuous press or horizontal centrifuge An efficient press or centrifuge and the maintenance of optimum curd characteristics and temperatures during washing are necessary to reduce the moisture content of the curd to 55–60 % and so minimize the amount of water to be evaporated during drying

The water from the press or centrifuge and any particles of casein which

escape are recycled to the penultimate washing stage With efficiently operated screens and optimum curd and washing conditions, the loss of fines in the wash water can be minimized However, the loss can be 1–2% of the yield in an efficient plant [3] Hydroclones have been used to recover some of these fines[31] and an automatic desludging separator is considered economical under European conditions [4] The fines so obtained may be dissolved in sodium hydroxide and recycled for coagulation

During the acidulation and early washing stages in casein manufacture, there are sometimes problems because of a tendency for curd particles to float It has been shown through studies on the density of casein curd particles[32] that this can happen only if the particles contain gas or air It is therefore necessary in lactic casein manufacture to minimize gas formation by bacteria and, for all types of casein, to avoid the incorporation of air into skim milk, steam and acid, if used

2.3. Drying, Tempering and Grinding

There have been a number of types of equipment developed for drying casein [3] Probably the most widely used in recent years is a vibratory type of drier developed in New Zealand [33] The curd passes through a mill to reduce it to even-sized particles which then travel by means of a vibratory action over trays of perforated stainless steel, transferring to successively lower trays, this is effected by means of a star-wheel activated by the vibration The heated air flows through the beds of curd from the bottom to the top, thus encountering layers of curd of increasing water content and giving improved efficiency of heat utilization The positive movement of the curd through the system gives very even drying and the system has the flexibility to cope with varying types of curd at differing treatment rates [3]

Other equipment recently described includes a granulator and a four-compartment fluidized bed drier in use in USSR[34] and a system for the mixing, comminuting and moving of casein [35]

Of particular interest is a new drying system—attrition drying [36] The drier features a fast-revolving (1800–2100 rpm) multi-chambered rotor and a stator with a serrated surface The action involves grinding the curd to very small particles thus exposing a large surface area to the hot air which conveys the curd through the drier Drying is very fast (1–2 s) and gives a product similar to ground, spray-dried casein The dryer has been installed in eight European dairy factories during the two-year period to early 1981 [36] A schematic of the dryer and associated equipment is shown in Fig 4

Attrition drying appears to offer more than an efficient drying process

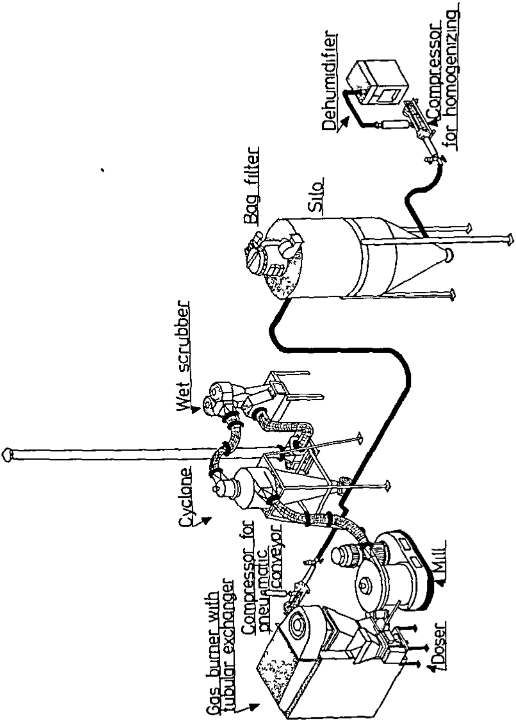

FIG 4 The attrition casein drier and associated equipment

ults similar to the PER of 2 45 (ANRC reference casein 2 50) reported in
ier studies [47] There is growing interest in the use of rennet casein as a
od ingredient, partly because of its suitability for use in making cheese
alogues and partly because of its good flavour stability [48]

4. CO-PRECIPITATES

n the manufacture of casein, only some 80% of the protein of skim milk an be recovered, as the whey proteins are soluble at pH 4 6 The desire to mprove protein recovery, and the concepts of increasing the nutritive value and the range of functional properties in milk proteins for use in foods, led to the commercial development of co-precipitates of casein and whey proteins [3] The early developments, mainly in the USA and USSR, have been extensively reviewed [3 6 7] The processes in the USA[49 50] involved heating the skim milk and using acid to form the co-precipitate The USSR process[51] was based on co-precipitating the proteins from heated skim milk by the addition of calcium chloride

Australian work on co-precipitates began[52] with modification of the USSR process to produce a curd which would withstand washing The technique that had been developed for mixing acid and skim milk in the manufacture of acid casein[18] was adapted to spray a calcium chloride solution into milk heated to 90–95 °C A holding tube followed the spray to provide suitable conditions for aggregation and syneresis of the curd before separation from the whey and then washing It was shown that the product could be dispersed, prior to spray-drying, by between 2 and 6% of sodium tripolyphosphate, depending on the water-binding capacity required

The level of calcium in the co-precipitate was observed to have a major effect on its functional properties and the process was further modified to produce well-washed co-precipitates of defined calcium content [53] The terms high-, medium- and low-calcium were used to define co-precipitates with calcium contents in the ranges 2 5–3 0%, 1 0–2 0% and 0 5–0 8% respectively Control of calcium level was achieved by varying the amount of calcium chloride added, changing the length of time at which the milk was held at about 90 °C and, for low- and medium-calcium co-precipitates, varying the pH of precipitation by acid The conditions used are summarized in Table 1

Figure 5 shows how the acid casein plant of Fig 2 was modified for the manufacture of co-precipitates The modifications made it possible to use the plant for either casein or co-precipitate manufacture

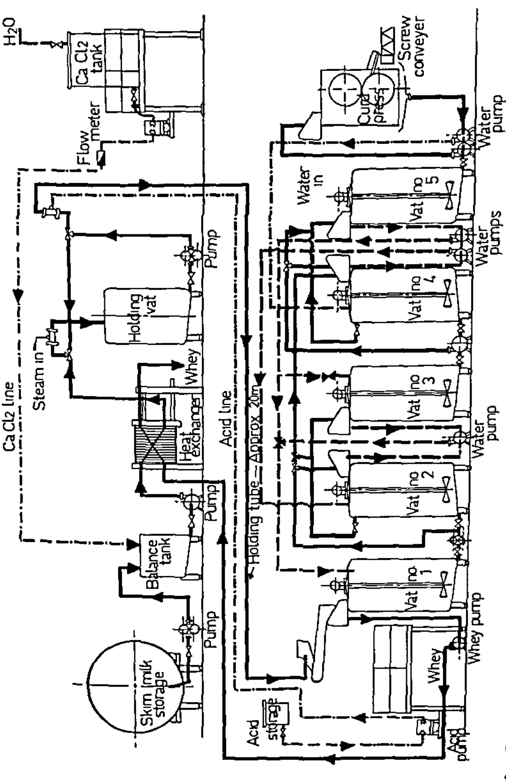

FIG. 5 Co-precipitate manufacture—Australian plant design ——, Product flow line; -·-·-, water flow line, - - -, acid or $CaCl_2$ flow line Reproduced from *Dairy Sci Abstr* by permission of the publishers

TABLE I

CONDITIONS USED IN MANUFACTURE OF CO-PRECIPITATES[53]

Co precipitate	*Time milk held at 90°C (min)*	*$CaCl_2$ added (% w of milk)*	*Acid added*	*pH of precipitation*
High-calcium	1–2	0 2	No	5 8–5 9
Medium-calcium	10–12	0 06	Yes	5 3–5 6
Low-calcium	15–20	0 03	Yes	4 6–4 8

There have been a number of recent studies on the variables in manufacturing co-precipitates and on modifications to the process [7] Some of these studies involved increasing the amount of whey protein in the co-precipitate by the addition of whey to skim milk or buttermilk [54–56] Other studies related yield and composition of the co-precipitate to such factors as pH and calcium content of the heated mixture,[57] the influence of added whey[58] and pH adjustment of the skim milk [59] The major study in ref 59 showed that the addition of acid to the skim milk was effective in increasing the amount of soluble calcium, as an alternative to the addition of calcium chloride for increasing the strength of the curd Useful data were given on temperature and time for heating the skim milk, precipitation conditions, recovery of whey proteins and yields at differing calcium levels In general, these various studies have confirmed the earlier observations[53] and have also indicated ways in which the process can be optimized to suit differing approaches to the overall system of manufacture

A considerable number of data on the properties of co precipitates in relation to their solubility in various solvents and to their applications in foods are given in refs 3, 7, 53, 56, 57, 59 and 60 Estimations of protein efficiency ratios confirmed the expected improvement over casein in nutritive value [47]

5. CASEINATES, MILK PROTEINATES

Many of the food applications for milk proteins require that they be in a water-soluble form However, there are notable exceptions For example, in the Australian milk biscuit,[61] the requirement was for a milk protein preparation which could be added at a high level to a biscuit dough without competing unduly with the flour for the small amount of available water A high-calcium co precipitate, carefully controlled in respect of pH and

calcium level and dispersed for spray-drying in about 2% of sodium tripolyphosphate, provided the necessary properties.[62] Calcium caseinate also fulfils particular functional requirements which include low solubility.

The most common technique for preparing a calcium caseinate dispersion for spray-drying involves the reaction of a good-quality acid casein with calcium hydroxide to achieve a calcium content of 1.0–1.5% at a pH of about 6.5.[3] Care is necessary in the application of heat during the dispersion process, as there is increasing aggregation of the protein and possible gel formation as the temperature increases.[63,64] The preferred raw material is freshly precipitated and washed curd, which should be soft and well hydrated—about 65% moisture.[64] Lower-moisture curd, resulting from high cooking or washing temperatures, leads to an increase in the amount of sedimentable material in the dispersion. With care in both temperature control and processing of the acid casein, concentrations of 25–30% can be prepared for spray-drying. However, in practice, lower concentrations may be necessary to avoid gelation if the concentrate is pasteurized before spray-drying.

Other recent reports on the production of the less usual caseinates include two on citrated caseinates, considered to be particularly desirable for use in dietetic and infant nutrition. Lactic casein of 60–65% moisture content was comminuted in a colloid mill with sodium and potassium citrates[65] or these citrates plus sodium carbonate[66] to obtain a mixture of about 20% total solids for spray-drying.

Soluble caseinates of importance have sodium, ammonium, potassium or magnesium as the cation. Sodium caseinate is by far the most commonly used in foods. To obtain a bland-flavoured caseinate, it is normal to use a fresh acid casein curd, dissolved in the appropriate alkali and spray-dried.[3,67] The main difficulties in the manufacture of spray-dried sodium caseinate are related to the logarithmic increase in the viscosity of caseinate solutions as their concentration increases and to the tendency for the reaction of the alkali to be impeded by the relatively impervious gel which forms on the surface of casein particles in the presence of alkali. A dissolving technique which was found satisfactory in practice[6,68] involves adding fresh wet curd and alkali progressively to water in a vat equipped with a powerful agitator and with a large-capacity centrifugal pump to apply shearing forces to curd particles during recirculation. Towards the end of the process it becomes very difficult to dissolve freshly added curd, so the mixture is then passed through a colloid mill. A later detailed study of factors affecting the rate of conversion of curd to sodium caseinate[69] led to the proposal that the fresh curd and water be passed first through a colloid

mill to give a fine slurry of about 25% solids content, and then mixed with sodium hydroxide solution before passing into an agitated vat with recirculation facilities Careful control of pH is essential The minimum viscosity for sodium caseinate is in the pH range 6 6–7 0 [67,70] In practice, it is better to maintain a pH below this value during dissolving and make any adjustment when the curd is finally in solution [68 69] It is also important to avoid exposing casein to high pH and temperature during dissolving, as this can lead to loss of lysine and serine and the production of degradation products such as lysinoalanine [71]

The viscosity of the soluble caseinates limits the concentration at which they can be spray-dried, normally to only about 20% solids at 90–95°C There is an optimum viscosity for spray-drying, depending on the atomization system used As the intrinsic viscosity of casein may vary throughout the year, it is better to standardize the viscosity and temperature of the solution to be spray dried rather than to standardize on solids content [68 69]

The low level of solids at which sodium caseinate is dried means that the output from the drier is only about 25% of that when skim milk is dried This, and the low bulk density of the powder, add substantially to the costs of drying, packaging and transport A number of approaches have been taken in an effort to reduce these costs

(i) Spray-dried caseinate has been ground in a pinmill to increase its bulk density [72]
(ii) Roller-drying has been used on both sodium caseinate solutions of higher solids levels[67] and on mixtures of fresh casein curd and alkali [73]
(iii) Granular caseinates have been produced by reducing the moisture content of casein curd to such a level (below 40%) that a free-flowing mass can be maintained by agitation after alkali (carbonate or bicarbonate powder) has been added After time for conversion, the mixture could be dried and ground in conventional casein equipment [67 74]
(iv) Ammonium caseinate in granular form has been made simply by passing ammonia gas through low moisture casein and removing excess ammonia with a stream of air [75]
(v) Finally there is a report[36] of the first commercial use of the attrition drier for making caseinates The drier was fed with the free flowing curd/alkali mixture described earlier[74] to produce a highly soluble caseinate with a bulk density much higher than that of spray dried caseinate

The account above illustrates the numerous possibilities for making soluble caseinates with specific functional properties and for improving the economics of their production The range has already been increased by the addition of milk proteinates from co-precipitates and rennet casein dispersed or rendered soluble by treatment with alkali or sodium tripolyphosphate

It has also been shown that casein and co-precipitates can be dispersed in concentrations suitable for spray-drying by the use of various acids The products had unusual functional properties [76] In the near future, the range is likely to be further increased by the advent of milk protein concentrates made by the ultrafiltration of skim milk, then drying In such concentrates the casein is still present in the original micellar form with all the interesting properties of the casein micelles in skim milk

6. FLAVOUR

In the industrial applications of casein, the main emphasis is on adhesive strength, colour and viscosity for acid caseins, and on the colour and transparency of the plastics made from rennet caseins For use in foods, the emphasis tends to be on the functional properties of the type of milk protein in the particular food system but, for many applications, nutritional value and flavour are important There are substantial data on nutritional value, casein being the standard with which the PERs of proteins are compared Co-precipitates and whole-milk proteins have higher PERs because of the inclusion of the whey proteins In respect of flavour, however, there are some problems The high calcium-phosphate products, such as rennet casein, are noted for bland flavours and good storage stability [48] However, the acid caseins and, generally, the caseinates, tend to develop, on storage, off-flavours variously described as 'gluey', 'stale', 'burnt feathers' or 'musty' [3] In studies on acid casein, a large range of volatile components were found in the steam distillate [77] The findings suggested that the 'gluey' flavour resulted from a mixture of compounds with a synergistic effect from *o*-aminoacetophenone Non-enzymic browning reactions appeared to be involved Modification of the acid casein manufacturing process so as to avoid possible browning reactions certainly gave a product of improved flavour stability [3] Later studies[78] indicated that the generally better flavour stability of casein made by acid injection compared with that of lactic casein is probably due to better control of the pH of precipitation and/or limiting the formation of flavour precursors due to proteolysis in lactic casein manufacture These authors[78] also considered *o*-aminoacetophenone to have a major role in the off-flavour

7. INDUSTRIAL USES

The developments previously described have been, in general, associated with the increase in food uses of milk proteins These uses are the subject of a separate chapter of this book However, the industrial uses of casein are still of importance Estimates of industrial uses in 1978[2] totalled about 45 000 tonnes of which, perhaps, 2000 tonnes were for the manufacture of casein fibres and the balance was almost equally divided between uses for papercoating and for the manufacture of plastics and adhesives

The literature in this field has recently been reviewed [2] That review gives a good covering of uses in papercoating, sizing, fibre production, paints, leather finishing, animal foods and plastics, as well as some references to miscellaneous uses and a general covering of uses in glues The literature on casein glues dates back to over 40 years and access to it is often difficult It was considered useful, therefore, to record here some details

Casein glues were first manufactured in Europe early in the 19th century However, the quantity used was small until the first World War when a water-resistant glue was needed for the construction of military aircraft—then made chiefly of wood [2,79] The use of casein glues spread to other wood working industries

Two forms were marketed prepared, or ready-mixed, and wet-mix glues The formulae of ready mixed glues vary considerably, a number being patented In general, they consist of casein, lime and such materials as sodium fluoride, borax and sodium phosphate [80] Typical wet mixed glue formulae[80] were

(i) 220–250 parts of water mixed with 100 parts of lactic casein, add 20–30 parts of calcium hydroxide in 100 parts of water, add 70 parts of sodium silicate (s g 1 38) Another similar version contained 2 to 3 parts of copper chloride or sulphate to increase water resistance and resistance to moulds and bacteria The 70 parts of sodium silicate may be replaced by the sodium salt of any acid which forms an insoluble calcium salt, e g sodium carbonate (14 6 parts), trisodium phosphate (15 0 parts, anhydrous) and sodium fluoride (11 6 parts)

(ii) 200 parts of water, 100 parts of lactic casein, 10 parts of sodium hydroxide in 50 parts of water

These formulae refer to lactic casein The use of hydrochloric acid casein was studied using the same formulae [81] The results showed some differences but it was concluded that either form of acid casein could be

used with confidence It was also found possible to use rennet casein for glues either by treating the casein with acid[80,82] before making a glue containing an 'alkaline' sodium silicate or by using a 'neutral' sodium silicate without acid treatment of the casein

8. CONCLUSIONS

It should be evident from this account that substantial progress has been made over the last 25 years or so in developing processes for the manufacture of casein, caseinates and co-precipitates The dairy industry now has available the technology needed to make a wide range of high-quality products with the functional properties needed for various food and industrial applications Highly nutritious products of good flavour can now be manufactured The future will probably see extension of the range through the advent of such processes as ultrafiltration which permit the concentration of both casein micelles and whey proteins in their natural soluble form

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Chapter 11

INDUSTRIAL ISOLATION OF MILK PROTEINS: WHEY PROTEINS

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1. INTRODUCTION

In the manufacture of cheese or casein from milk, curds are formed by the action of rennet-type enzymes and/or acid Whey is the liquid remaining after the recovery of these curds The whey contains more than half the solids present in the original whole milk, including 20% of the protein and most of the lactose, minerals and water-soluble vitamins Large quantities of whey are produced worldwide In general the manufacture of 1 tonne of cheese or casein results in the production of 8 or 25 tonnes of liquid whey, respectively Thus total world production of whey in 1980 was approximately 75 million tonnes from cheese and 4 8 million tonnes from casein

Disposal of whey is a continuing problem When cheese was produced in small plants in the rural areas, the whey was fed to pigs, spread on fields or dumped into rivers However, whey has a biochemical oxygen demand of 35 000–45 000 g/litre, and 100 litres of whey has a polluting strength equivalent to the sewage produced by 45 people Over the last 20 years the increasing pressure of anti-pollution regulations and the cost of disposal to municipal sewage plants, along with the consolidation of dairy processing into large units, have made it impractical to continue to dispose of large quantities of whey by the traditional methods

Also, over the last 20 years, there has been a recognition that the proteins and lactose in whey are valuable nutrients which should not be wasted This, coupled with the growth of food technology and the use of functional proteins in processed foods, together with the emergence of commercial

methods for the economic recovery of such proteins from whey, has resulted in a marked difference in attitude towards whey, which is no longer being seen as a waste product but rather as a source of valuable constituents which can be used by the food industry.

2. WHEY

Whey is a dilute fluid, that from bovine milk containing about 65 g/litre solids, of which the major constituents are lactose (70–80 %) and protein (9 %). In general, there are two major types of whey[1,2]: sweet whey from the manufacture of cheese or casein from milk by the action of rennet-type enzymes with relatively little or no acidity development, and acid whey where the milk is coagulated primarily with acid. Sweet whey has a minimum pH of 5.6 and acid whey a maximum pH of 5.1.[1] Acid whey has a

TABLE 1
WEIGHTED SEASONAL AVERAGES OF COMPOSITION AND pH OF WHEYS FROM RENNET, LACTIC AND MINERAL ACID CASEINS AND CHEDDAR CHEESE MANUFACTURE[a]

	Composition (g/l)			
	Rennet casein	*Lactic casein*	*Mineral acid casein*	*Cheddar cheese*
Total solids	66	64	63	67
Protein ((TN − NPN)[b] × 6.38)	6.2	5.8	5.8	6.2
NPN	0.37	0.40	0.30	0.27
Lactose	52.3	44.3	46.9	52.4
Minerals (as ash)	5.0	7.5	7.9	5.2
Milk fat	0.2	0.3	0.3	0.2
Phosphate	1.0	2.0	2.0	0.5
Calcium	0.5	1.6	1.4	0.4
Sulphate	0.7	0.5	2.8	0.6
Magnesium	0.07	0.10	0.11	0.08
Sodium	0.53	0.51	0.50	0.50
Potassium	1.45	1.40	1.40	1.50
Chloride	1.02	0.9	0.9	1.0
Lactate		6.4		2.0
pH	6.4	4.6	4.7	5.9

[a] Data from analyses at New Zealand Dairy Research Institute.
[b] TN = total nitrogen, NPN = non protein nitrogen.

relatively higher mineral (measured as ash, also known as salt) concentration If the acidity has been formed by the action of starter bacteria, the lactose concentration is reduced with a corresponding increase in the concentration of organic acids (generally lactic, but also citric, acetic, etc) The composition of whey varies with the composition of the milk, the cheese or casein type, the processing methods, etc [3–9] Some typical compositions of New Zealand wheys are given in Table 1

3. WHEY PROTEINS

The major protein constituents of whey are β-lactoglobulin, α-lactalbumin, bovine serum albumin, the immunoglobulins and proteose-peptones There are several minor whey proteins including lactoferrin, lactollin, glycoprotein and blood transferrin Information from reviews[10–14] on the protein content of wheys and the properties of the individual components is summarized in Table 2

Whey from bovine milk contains 4–7 g protein/litre, the concentration depending on the type of whey, the stage of lactation and the processing conditions used in the manufacture of the cheese or casein The whey proteins are mainly large globular proteins β-Lactoglobulin, which makes up

TABLE 2

THE WHEY PROTEINS OF BOVINE MILK

	Approximate proportion of the skim milk protein[13] (%)	*Approximate concentration in whey*[10] (g/l)	*Proportion of total whey protein* (%)	*Iso electric point*[13] (pH)	*Approximate molecular weight*[13] (daltons)
β Lactoglobulins	7–12	3 0	50	5 35–5 49	18 300
α Lactalbumin	2–5	0 7	12	4 2–4 5	14 000
Immunoglobulins	1 9–3 3	0 6	10	5 5–8 3	15 000–1 000 000
Bovine serum albumin	0 7–1 3	0 3	5	5 13	69 000
Proteose peptone fraction	2–6	1 4[a]	23		4 100–40 800
Total whey proteins	15–22	6 0	100		

[a] Includes proteose peptones, residual casein and a number of minor proteins

half the whey proteins, has a monomer molecular weight of 18300 daltons but exists as a dimer between pH 3 5 and 7 5 The immunoglobulins comprise a mixture of glycoproteins of different sizes and are grouped together because they have a common antibody activity The proteose-peptone fraction contains a mixture of glycoproteins and phosphoproteins with a range of molecular weights The major whey proteins contain significant numbers of sulphydryl groups—β-lactoglobulin, α-lactalbumin and bovine serum albumin contain 1 6%, 1 9% and 1 9% sulphur respectively

The undenatured native whey proteins are soluble at all pH values, a factor which distinguishes them from the caseins Except for the stable proteose-peptone fraction, whey proteins are sensitive to temperatures above 60°C, the degree of denaturation depending on the protein component, total protein and solids concentrations, pH, *ionic strength*, temperature and time of exposure Whey proteins are noted for their high nutritional value[7 8 15-20] The native proteins have a high degree of functionality Thus, they are soluble over a wide pH range, can form heat-induced gels, can be whipped to form stable foams and can emulsify significant quantities of fat[21]

4. WHEY PROTEIN PRODUCTS

Significant quantities of whole whey products are produced commercially and include whey powders, whey concentrate and whey cheese The protein content, on a dry basis, is only 10–15% and the protein, generally, does not play a major role in the foods or feeds incorporating such whey products Whey proteins are also recovered in some types of cheese and in combination with casein or microbial proteins, often as a means of increasing yield, but the whey proteins also can play a significant nutritional role in such products

To take greater advantage of the nutritional and functional properties, many processes to recover whey proteins in a more acceptable and concentrated form have been investigated, and some are in commercial operation These include demineralization (electrodialysis or ion-exchange) and lactose crystallization to produce modified whey products (demineralized whey, delactosed whey and demineralized, delactosed whey) with 10–25% protein on a dry basis Whey protein concentrate (WPC) is a relatively recently used term applying to soluble forms of whey protein products containing 25–95% protein on a dry basis and produced

by ultrafiltration, polyphosphate precipitation, gel filtration or adsorption, often coupled with demineralization and lactose crystallization

One of the oldest methods used to isolate whey proteins involves heat denaturation and acid precipitation The product, traditionally known as lactalbumin, retains its nutritive value, but, because it is denatured and insoluble in water, lacks the other functional properties of the native proteins

Whey protein isolation techniques have been reviewed by a number of authors [14 22 29] Methods known to be in commercial or advanced pilot-scale use are shown in Fig 1 Other methods, noted from the scientific or patent literature, are given in Table 3 Most of the latter appear not to have advanced beyond laboratory-scale work despite extensive studies in some cases However, many companies do not publicize their methods of production and some of the techniques given in Table 3 may be in commercial use Details of the apparently non-commercialized methods are not discussed in this paper and further information should be sought in the references given

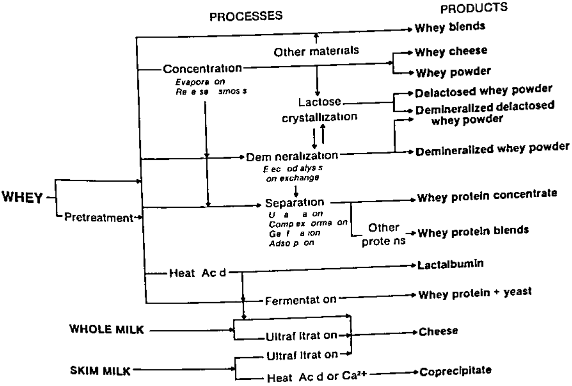

FIG 1 Industrial isolation of protein products from whey showing some of the processes and unit operations used in commercial or advanced pilot scale production Some of the complex interrelationships between the processes are illustrated For clarity, final separation concentration drying and packaging steps in the processes have been omitted

TABLE 3
METHODS FOR THE RECOVERY OF WHEY PROTEINS WHICH APPEAR NOT TO HAVE BEEN USED ON A COMMERCIAL SCALE

Method	*Reference*
Precipitation by	
carboxymethylcellulose	30–35
ferric salts	36–39
alcohols	40, 41
tannin	42
polyacrylic acid	43–45
sodium lauryl sulphate	46
bentonite and lignosulphonate	47
chitosan	48
tannery waste	49
Co-precipitation with plant protein	50–53
Ion-exchange	54
Foam concentration	55, 56
Dialysis	21, 41
Ultracentrifugation	57
Electroflotation	58

4.1. Whole-whey Products

World production of dried whey in 1980 was 995 000 tonnes[59,60] and has been growing at an annual rate of about 9% since 1965

Whey is usually concentrated by evaporation to 50–60% total solids before drying To avoid protein denaturation, temperatures less than 70°C are used In recent developments, reverse osmosis has been used to concentrate the whey up to 25% solids, either before transport to central processing facilities or as a means of increasing the capacity of existing evaporators[60–64] Most whey powders are produced by spray-drying, although roller-drying techniques are in common use

Special methods are used to produce non-hygroscopic and non-caking whey powders[65–68] The whey concentrate is cooled quickly to 28–30°C, seeded with lactose, held to promote mutarotation (conversion of β-lactose to α-lactose, which is less hygroscopic) and then further cooled slowly over a period of hours to 15–18°C to crystallize up to 85% of the lactose The concentrate is then spray-dried, in a single stage to produce a dense powder with small agglomerates, or in a two-stage process to produce a coarse agglomerated powder In the two-stage process, which is more applicable to acid wheys, low temperatures are used in the first stage to give a product

of about 12% moisture This intermediate product is held for 3–5 min while more lactose crystallizes as the α-monohydrate, before further drying in a secondary drier

The high mineral concentration in whey powder can adversely affect the flavour and nutritional value of the product Better-quality whey powders, particularly for use in infant and special diet foods, are produced by demineralization of sweet wheys by electrodialysis and/or ion-exchange [69,70]

Whey powders find their main use as stock feeds and baking or confectionery ingredients, often as a replacer for the more expensive skim milk (non-fat dried milk) powder [71] Frequently, the protein does not play a major role An exception is infant formulae, particularly those attempting to simulate human milk in which the ratio of whey to casein protein (60 40) is markedly different from that of bovine milk (20 80) [16]

Significant quantities of whey concentrates (35–50% total solids) are produced commercially by evaporation [60] Uses are similar to those of whey powder

Whey cheeses, manufactured from heated or condensed whey, are popular in Norway (Mysost), Malta (Ricotta), Italy (Ricotta) and Yugoslavia (Ziger) [72,73]

4 2. Recovery of Whey Proteins by Incorporation in Other Products

4 2 1 Cheese

Whey proteins are being recovered in processes designed to increase the yield of cheese from milk In one of these the proteins are precipitated from the whey, recovered and added to the cheese milk In another, milk is ultrafiltered before cheesemaking, which proceeds without the conventional whey removal step

In the Centriwhey' process[74–77] cheese whey is separated and clarified, heated to 97 °C and held for 20 min, acidified to the protein isoelectric point (pH 4 7–5 0), held for 75 s, cooled to 40 °C and fed to a self-desludging clarifier to recover the precipitated whey proteins in a slurry of about 16% total solids The slurry is added, by continuous injection, to the cheese milk prior to pasteurization About 92–93% of the whey proteins are recovered and incorporated in the cheese Cheese yield is increased by 10 to 14% depending on the cheese type Extra milk-fat is required to maintain the correct milk fat/solids-not-fat ratio in the cheese

In a process which is gaining widespread use, particularly for soft cheese,[78,79] milk (before or after milk fat separation) is ultrafiltered to give a retentate or liquid precheese[80] which has a composition close to that of

the final cheese, e g 39 5% total solids for Fetta [81] A high-fat cream is mixed with the retentate and rennet and starter are added to the precheese which is placed in the normal moulds The cheese is then treated in the normal manner except that little or no whey is expelled by syneresis and the whey proteins are incorporated in the cheese The advantages are summarized by Bundgaard *et al* [82] and the process is used commercially in the production of Fetta cheese,[81] fresh soft cheese and Camembert [78 79] Yield increases in soft cheese of up to 30% are claimed [81] Hard cheeses of the Cheshire and Cheddar types have been produced experimentally, but cheese quality was not completely satisfactory [83]

4 2 2 Co-precipitates

Co-precipitates contain combinations of caseins and whey proteins precipitated together from heated skim milk The initial heating (>85°C) of the milk denatures the whey proteins, some of which form complexes with the caseins The mixture of proteins is precipitated by the addition of acid (pH 4 6–5 6, 55–65°C) or soluble calcium salts (pH 5 8–5 9, 65°C) The co precipitated curd, containing 60–75% of the whey proteins from the milk, is washed, de-watered and dried Compared with casein, co-precipitates give a 7–21% higher yield of protein, have a wider range of functional properties and have a higher nutritional value [84–86] A total milk proteinate containing all the casein and whey proteins of milk in a single undenatured protein complex was announced recently [87]

4 2 3 Whey Proteins and Yeast

Whey fermentation by lactose metabolizing yeast is a process operated commercially in a number of countries [88–90] In some of the processes, the whey proteins are recovered with the yeast, increasing the yield and, because yeasts are deficient in the sulphur amino acids present in the whey protein, improving the nutritional value of the yeast The process and the products were reviewed by Muller[91] and Marth [92 93] In the process operated by the Societe des Alcools du Vexin (SAV), the lactose in the whey is partially fermented and the whole liquor concentrated and spray-dried In the 'Wheast' process, which was operated by the Knudson Milk Products Co,[94 95] the whey proteins were heat-precipitated, the lactose fermented and the yeast and whey proteins recovered together by centrifugation, washed and roller-dried In another proposed variation, the whey proteins and yeast are concentrated and fractionated from the other whey components by ultrafiltration [96] The process is operated commercially but there is likely to be a trend to recover the whey proteins

separately and convert the lactose into yeast as a source of a lower quality protein However, research work is continuing on the joint recovery [97]

4 2 4 Whey Blends

A recent trend in food protein products is the development of a wide range of protein blends formulated from whey, whey protein concentrates, caseinates and non-dairy proteins The products are produced by dry or wet blending, or co-precipitation followed by heating to modify properties, blending with other additives and enhancers, and drying [98-100] The list of such blends is impressively large Many are tailor-made to meet specific functional property needs, and increased production, with greater use of whey protein, is likely in the future as the functional and chemical properties of the whey proteins, together with their interactions with other ingredients, are understood better

4.3. Modified Whey Powders

Whey powders may be modified or enriched in protein by reducing the lactose and mineral concentrations of the whey

Lactose is traditionally produced by concentrating whey and crystallizing the lactose, which is recovered by centrifugation or filtration The mother liquor remaining contains 38–45% total solids including whey proteins, salts and lactose In older methods of lactose production, the protein was generally denatured and used for stock feed However, if high temperatures (i e $>70\,^{\circ}C$) are avoided during the concentration steps, the whey proteins can be recovered in an undenatured form Spray-dried mother liquor (delactosed whey powder) contains about 25% protein

Demineralization (10–90% removal of minerals) is used to reduce the mineral concentration, the high level (up to 25%) of which limits the uses of dried mother liquor

4 3 1 Demineralization

Both electrodialysis and ion-exchange are used to demineralize whey (for the production of demineralized whey powder) or mother liquor Electrodialysis[69 70 101a 102] is a membrane process in which an electric current is used to remove the mobile salt ions (Fig 2) The cation-selective membranes contain covalently bonded anion groups (e g SO_3^{2-}) whilst the anion-selective membranes have positively charged quaternary amine groups In the figure the cations in whey are represented by Na^+ and the anions by Cl^- Cell pairs, each comprising a cation and an anion membrane, are arranged in a stack between two electrodes Whey is passed

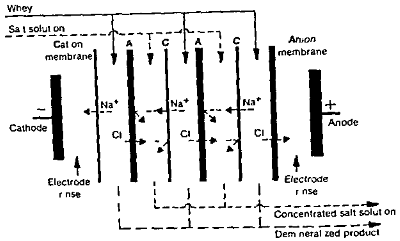

FIG 2 A schematic representation of electrodialysis

through alternate cell pairs and a salt stream through the remaining pairs Under the influence of the applied potential difference (typically 1 5–4 5 V/cell, current density 5–20 mA/cm^2 of membrane) the cations in the whey will tend to migrate towards the cathode, displacing cations from the cation membrane into the brine stream The cations in the brine stream are rejected by the anion membrane, prevented from migrating further and are thus concentrated in the brine stream Conversely the anions, tending to migrate to the anode, are rejected by the cation membrane and are also concentrated, electroneutrality is thus maintained in the brine stream

In commercial electrodialysis operations, batch (residence time up to 6 h), semi-continuous and continuous (up to 20 min) modes of operation are used Temperatures employed are either below 10 °C (to limit microbial growth) or between 30 °C and 40 °C (higher efficiency because of increased ionic mobility, but limited by the temperature resistance of the membrane and the need to avoid protein denaturation) Mineral removal is limited to about 60 % to prevent precipitation of the protein For sweet wheys the process is more efficient, because of the higher initial mineral concentration, if concentrated whey is fed to the electrodialysis stack A variation of electrodialysis, known as transport depletion, replaces the anion membrane, which can be fouled by precipitated protein, with a neutral membrane[103–105]

Ion exchange[69,70,101b,106] involves solid beads or resins containing bound groups that carry an ionic charge, either positive or negative, in conjunction with free ions that can be displaced by ions of the same charge type in the solution being treated Most ion-exchangers in commercial use

are made from polystyrene co-polymerized with divinylbenzene Cation resins usually contain bound sulphonic acid groups Strongly basic anion resins contain quaternary ammonium groups whereas weakly basic resins contain secondary and tertiary amine derivatives The reactions that occur in ion-exchange can be represented by the following equations, where R indicates the group bound to the resin

Cation exchange

$$R{-}H + Na^{+} \rightleftarrows R{-}Na + H^{+}$$

Anion exchange

$$R{-}OH + Cl^{-} \rightleftarrows R{-}Cl + OH^{-}$$

In practice, the resins are usually used in columns During demineralization whey is pumped in sequence through two columns In the cation column, which is initially saturated with H^{+} ions, dissociated cations in the whey (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, etc) are exchanged for H^{+} ions In the anion column, OH^{-} ions are exchanged with dissociated anions (PO_4^{3-}, Cl^{-}, $CH_3CH(OH)COO^{-}$, etc) The minerals in the whey are thus replaced by H^{+} and OH^{-} ions When the resin is exhausted, i e saturated with ions from the whey, it is washed and regenerated with acid (cation) or alkali (anion) and the cycle repeated Single-column operation with mixed resins is possible, but the resins must be separated for regeneration For whey demineralization, operation is generally at temperatures less than 8 °C, and minimum prior heat treatment is given to the whey to prevent loss of protein

In general, capital costs are higher and operating costs lower for electrodialysis than for ion-exchange [70]

4 3 2 Demineralized, Delactosed Whey Powder

In a typical process for the production of delactosed, demineralized whey[107,108] (Fig 3), pasteurized whey is concentrated by evaporation to 20–30 % total solids, adjusted to pH 6 2–6 4, the concentrate clarified, and demineralized by electrodialysis The demineralized material is further concentrated to 40–60 % total solids by evaporation at temperatures less than 70 °C Lactose is recovered by crystallization The mother liquor is further concentrated and spray-dried as a whey protein concentrate powder containing 14–35 % protein (see also refs 103–105, 109, 110)

Francis[111] claimed that removing the lactose prior to electrodialysis allowed both high- and low-heat wheys to be processed without precipitation of the protein in the electrodialysis step Whey is concentrated by

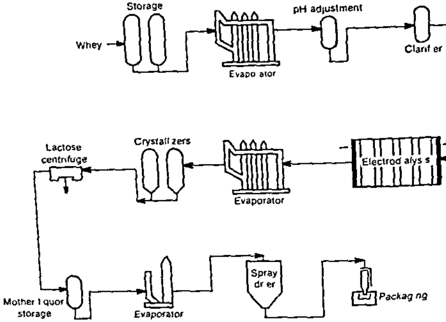

FIG 3 A schematic of a process to produce demineralized delactosed whey powder containing 14–35 % protein [107,108]

evaporation to 50–60 % solids and 40–60 % of the lactose crystallized The mother liquor is centrifuged and screened to remove the lactose Residual lactose crystals are dissolved by heating to 43–50 °C and the mother liquor is clarified to remove insoluble protein, adjusted to pH 3 9–4 2 for cottage cheese whey or 4 7–6 5 for Cheddar cheese whey before electrodialysis at up to 33 % total solids to remove 20–55 % of the minerals It is also claimed that the ratio of the concentration of sodium and potassium to that of calcium is reduced, further enhancing the nutritive value of the product

4.4. Whey Protein Concentrates Manufactured by Ultrafiltration

In the last decade the emergence of reliable and hygienic ultrafiltration units for commercial processing has resulted in a dramatic increase in the production of whey protein concentrates by this technique In 1970, there were no commercial plants operating on whey In 1981, Maubois *et al* [199] estimated that 7–8 % of the world's whey was subjected to ultrafiltration De Boer and Hiddink[113] estimated an installed membrane area of 15 000 m^2 for whey processing worldwide This estimate was based on data from only five manufacturers (Abcor, De Danske Sukkerfabrikken, Paterson Candy International, Rhone Poulenc and Romicon) Inclusion of equipment from Dorr Oliver, Ladish-Triclover and Wafilin, together

with sales since 1980, will result in a significant increase of that estimate In the USA in mid-1981 there were at least 46 ultrafiltration plants sold for whey processing with a combined capacity in excess of 14 000 m^3/day Almost half of these plants have been purchased since 1979 (Horton Inc., private communication) In Australia and New Zealand seven commercial plants are processing whey by ultrafiltration and at least 20 plants are operating in Western Europe

4 4 1 Ultrafiltration

Ultrafiltration allows the selective separation of protein from lactose, salts and water in varying proportions under mild conditions of temperature and pH The related membrane process, reverse osmosis (also known as hyperfiltration), in general, removes only water and small amounts of solutes from whey, resulting in concentration of the total solids

Ultrafiltration is a physicochemical separation technique in which a pressurized solution flows over a porous membrane The membrane allows the passage of only relatively small molecules [114-116] Figure 4 demonstrates this schematically the retentate flows over the membrane, while under the influence of pressure, water flows through the membrane, together with the low molecular weight solutes The protein is retained by the membrane and is concentrated relative to the other solutes in the retentate Also any fat globules or suspended solids are retained in the retentate

The membranes used in ultrafiltration are asymmetric microporous structures, the effective layers of which appear to contain pores with

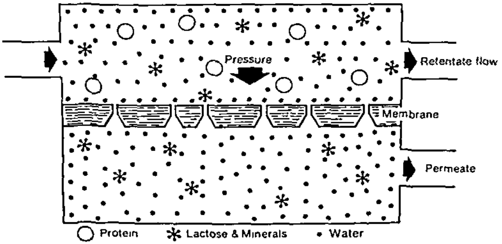

FIG 4 A schematic representation of ultrafiltration of whey

diameters ranging from 1 to 20 nm [201] The earlier versions of ultrafiltration membranes were manufactured from cellulose acetate, which is highly permeable to water, has low permeability to most water-soluble solutes and can readily be cast in thin films However, for commercial operations, cellulose acetate had a number of practical limitations It could not be used at high temperatures (many membranes were limited to less than 40 °C, although some could be used up to 50 °C), the pH range was limited to 3–8 and cellulose acetate was sensitive to attack by micro-organisms and some commonly used disinfectants Ultrafiltration membranes manufactured from synthetic polymers (e g polysulphone or polyamide) are now in common commercial use They are characterized by resistance to high temperature (up to 100°C) and can withstand a wide pH range (1–13) Some have a very high resistance to chlorine (widely used for sanitizing) and can be cleaned with the materials normally used in the dairy industry (e g nitric acid and sodium hydroxide) A new ultrafiltration membrane made from zirconium oxide and supported on graphite, is claimed to withstand temperatures up to 400 °C and to be resistant to all pH values[79] but it is not clear if such a membrane will be permitted to be used in the food industry

4 4 2 Theories of Ultrafiltration

Whilst there are several theoretical treatments in common use to describe the transport of solutes and solvents through ultrafiltration membranes,[117] the effects of various parameters on the flux (the flow-rate of permeate per unit area of membrane) are not adequately described by such theoretical models Nevertheless, empirical chemical engineering models have been developed which describe flux behaviour adequately enough to allow scale-up from pilot scale studies [115 117–121] In a study of the ultrafiltration of cheese whey, Howell *et al* [122] showed that the flux fell rapidly (in less than 5 s) from the clean water flux, and continued to decline at a lower rate for up to 10 min and then at a much slower rate for more than 5 h Other studies have shown that the flux of dilute whey solutions increases with increasing temperature, it increases with increasing pressure up to a limiting value of pressure, which, for a given system, is a function of the velocity of whey across the membrane surface (Fig 5), and it decreases with increasing protein concentration (Fig 6)

Coupled with the intrinsic membrane resistance, two other resistances are assumed to affect the flux, (i) concentration polarization and (ii) fouling Initial flux is high, but falls very rapidly[122] as concentration polarization occurs As permeate is removed through the membrane, the protein tends to accumulate at the solution–membrane interface In steady-

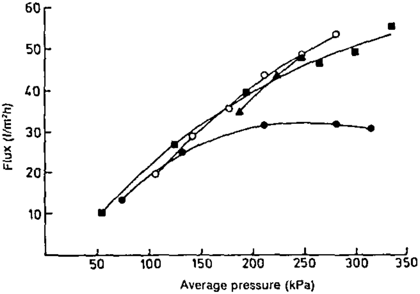

FIG 5 The effect of average pressure and recirculation flow rate on the flux of casein whey in tubular membrane equipment Flow rate (litre/s) ●, 0 5, ■, 1 1, ○, 2 3, ▲, 3 0 Note that at the low flow velocity (0 5 litre/s) there is a maximum pressure above which the flux does not increase with increasing pressure [152]

state conditions, the transport of solute by bulk flow towards the membrane is balanced by the combined effects of diffusive flow in the opposite direction and permeation through the membrane As the protein concentration at the interface increases, the resistance to flow increases Eventually the protein concentration may increase sufficiently for the protein to gel on the membrane [122–127]

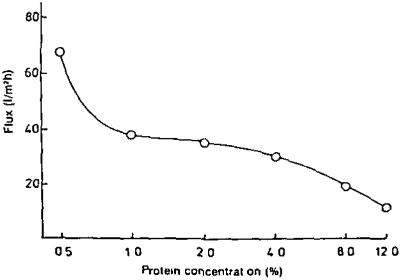

FIG 6 The effect of increasing whey protein concentration on flux of casein whey Note that protein concentration is on a logarithmic scale [152]

The design of commercial ultrafiltration equipment has been directed to reducing concentration polarization to a minimum and maximizing the flux, as this is the main determinant of the capital cost of an ultrafiltration plant [127] Coton and English[128] and Matthews and Houldsworth[129] discussed the factors to be considered in designing ultrafiltration equipment The International Dairy Federation[130] published a detailed survey of equipment available (Table 4), while Horton[131 132] discussed the advantages and disadvantages of each type

A further reason for deviations from ideal behaviour is *fouling* of the membrane (the second and third stage of the process described by Howell *et al* [122]) Some of the characteristics of fouling are similar to those of concentration polarization However, fouling reduces the flux of clean water, a factor not affected by concentration polarization Moreover, it is not possible to achieve steady-state operating conditions while fouling is occurring As fresh raw material is fed to the plant, fouling increases until eventually the process must be stopped and the membrane cleaned by chemical or physical methods Despite many studies the mechanisms of membrane fouling are not clearly understood In processing whey, proteins such as α-lactalbumin and β-lactoglobulin have been shown to form layers on the membranes[124 133] and it has been stated that calcium salts, lipid material, etc , are also involved in fouling [134] Poor-quality water will also foul membranes, particularly where high concentrations of iron oxides or silica are present [28] Some fouling is irreversible and the membrane must then be discarded and replaced Fouling may also be the consequence of concentration polarization, wherein the increase in concentration of the rejected species at the solution–membrane interface may lead to precipitation or gelation of components on the surface, or within the pores of the membrane

TABLE 4
ULTRAFILTRATION EQUIPMENT USED COMMERCIALLY FOR WHEY PROCESSING

Type	*Spacing*	*Manufacturers*
Open tubular	4–25 mm diameter	Abcor Inc , Paterson Candy International Ltd (PCI), Wafilin b v
Plate and frame	0 7–1 5 mm channel	De Danske Sukkerfabrikker (DDS), Rhone Poulenc
Flat leaf	1 0–2 3 mm	Dorr Oliver Inc
Hollow fibre	0 5–1 5 mm diameter	Romicon Inc
Spiral wound	0 9–1 2 mm channel	Abcor Inc , Ladish–Triclover Co

While aspects of plant design can affect membrane fouling, major efforts at reducing fouling during ultrafiltration have been directed at physical and chemical pretreatments of the whey [28 113 134] Whey pretreatments used to increase flux during ultrafiltration, to prevent fouling of the membranes and to modify the properties of the whey protein concentrate include

(i) Holding sweet whey at elevated temperatures (55 °C) for one to two hours before processing, which has been claimed to improve membrane processing rates, probably because calcium phosphate is able to separate from the whey However, this treatment did not affect the processing of acid whey [135]
(ii) Clarification (gravity settling, centrifugation or filtration),[136 137] sometimes preceded by calcium addition,[138] pH adjustment[139] or demineralization [140]
(iii) Heating, also sometimes preceded by demineralization, calcium addition or pH adjustment [141–143]
(iv) Demineralization [141 144]
(v) pH adjustment [145 146]
(vi) Sequestration of calcium [141]
(vii) Calcium replacement with sodium [113 147]

Preconcentration of the whey prior to ultrafiltration also improves the productivity of the process in some circumstances,[61 148 149] both because of the smaller quantity of permeate to be removed and because the preconcentration induces complexing of calcium salts and gives an increase in ionic strength [112]

The effects of pretreatments on flux are dependent on the type of whey being processed, the type of ultrafiltration equipment, the membrane type, and the operating conditions It is difficult, and even misleading, to extrapolate from one system to another In particular, pretreatments developed for one type of membrane (e g cellulose acetate) may not be applicable to the newer types of membranes The reasons for this are not clear Pretreatments can also have a profound influence on the composition and properties of the whey protein concentrates and permeates because of the altered whey composition and modification of the retentions (i e the degree of separation of a component from the solvent of various whey components) [142]

4 4 3 Commercial Whey Ultrafiltration

Ultrafiltration is being used to produce whey protein concentrate powders with protein contents ranging from 35–85 % [28 63 78 112 113 150–152] A

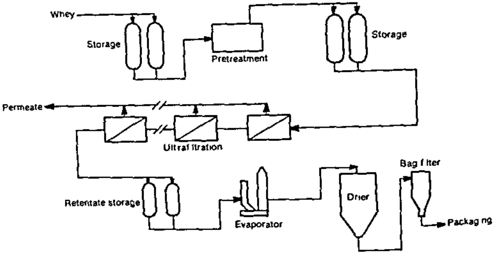

FIG 7 A schematic of a process to produce whey protein concentrates by continuous, multiple stages in-series ultrafiltration

typical flow sheet is shown in Fig 7 Whey, particularly sweet cheese whey, is separated to remove milk-fat as whey cream, and frequently pasteurized before pretreatment and storage Because of the variation in feed rate throughout the time of ultrafiltration (initially the flux is very high, falling rapidly as the initial quasi-steady state is reached, and then falling more slowly as the membranes foul), whey must be accumulated before ultrafiltration commences

Early commercial ultrafiltration plants were operated in batch mode (Fig 8) However, for microbiologically sensitive materials, such as whey,

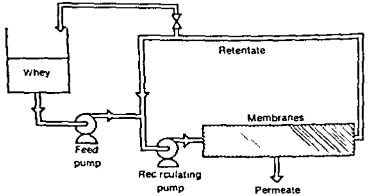

FIG 8 Process flow sheet for batch ultrafiltration in which whey at the desired process temperature and pressure is circulated through the membrane plant back to the feed tank while permeate is removed The residence time is equal to the batch time [152]

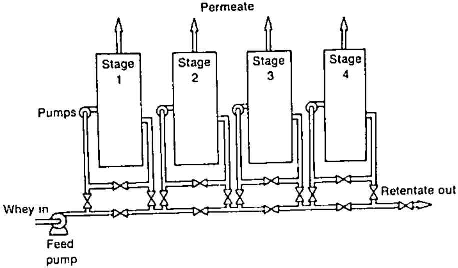

FIG 9 Process flow sheet for a continuous, multiple stages-in-series ultrafiltration unit [152]

batch processing is undesirable because of the long residence time and the danger of excessive microbiological growth although this can be minimized if plant is operated below 10 °C or above 48 °C The majority of commercial ultrafiltration plants recently installed in the dairy industry have been designed as continuous, multiple stages-in-series (4–15 stages) recirculation systems, generally operated at about 50 °C Figure 9 illustrates a unit with only four stages, but up to 15 stages are in use in commercial plants Feed enters the first stage and some retentate (partially concentrated with respect to protein) is passed to the second stage The remainder of the retentate returns to the recirculation pump and is mixed with incoming fresh feed The feed to each successive stage and the protein concentration in the retentate in each stage is higher than that of the previous stage The permeates from each stage are removed for processing To maintain velocities adequate to minimize concentration polarization and fouling, booster or recirculation pumps are used in each stage [152] Figure 10 shows a typical mass balance for a single stage

The protein/total solids ratio of the final retentate for a given feed and plant is controlled by the quantity of permeate removed The more permeate that is removed, the higher the protein/total solids ratio Ratios are limited to about 0 65 1, because the flux in the latter stages is excessively low as a result of the high viscosity of the retentate (>20 cP) To achieve higher ratios, water is added to the retentate in the final stages, at a rate less than the permeate flux The water dilutes the retentate, decreases the viscosity and, as it permeates, washes out lactose and minerals This process is known as diafiltration

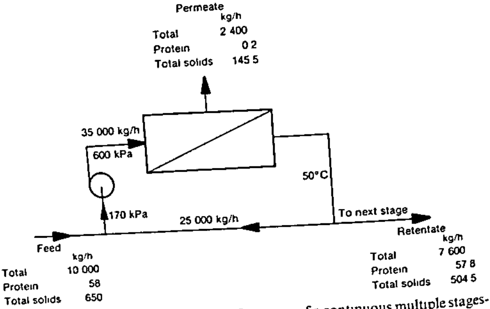

FIG 10 A typical mass balance for the first stage of a continuous multiple stages-in-series ultrafiltration plant

In most commercial plants the final retentate is relatively dilute and some further concentration is required before spray drying Low-temperature (*ca* 40 °C) evaporation to 15–20 % protein in the concentrate is a normal commercial practice Pilot-scale trials with reverse osmosis and high-pressure ultrafiltration have produce concentrates containing up to 35 % total solids (28 % protein)[153] and such processes may have advantages over thermal evaporation because of greater drying economy and lower thermal denaturation of the proteins

At least once per day, the ultrafiltration process is stopped and the membranes cleaned, to restore initial flux, and sanitized Modern plants are cleaned with sodium hydroxide, nitric acid and sodium hypochlorite solutions or hydrogen peroxide, although enzyme cleaning techniques, initially developed for cellulose acetate membranes, are still in commercial use[154]

The yield of product from a given whey is a function of protein concentration of the product and the retention characteristics of the membrane Table 5 contains some calculated yields from a particular whey fed to a particular ultrafiltration plant as a function of protein concentration taking into account protein loss because of the retention characteristics of the membrane Thus, the yield of final product decreases from 15 3 kg m^3 of whey at 35 % protein to 6 4 kg/m^3 at 80 % protein Other

TABLE 5

CALCULATED YIELDS OF PROTEIN AND TOTAL SOLIDS IN THE RETENTATE AND PERMEATE PER UNIT VOLUME OF WHEY FED TO A CONTINUOUS MULTIPLE STAGES IN SERIES ULTRAFILTRATION PLANT (kg/m^3 WHEY)

		Protein in final product (%)			
		35	*50*	*65*	*80*
Protein	Retentate	5 37	5 32	5 22	5 10
	Permeate	0 43	0 48	0 58	0 70
Total solids	Retentate	15 3	10 6	8 0	6 4
	Permeate	49 7	54 4	57 0	58 6

yield values will be obtained from other wheys and ultrafiltration plants with different retention characteristics Actual yields will also be lower because of processing losses, etc

The disadvantages of ultrafiltration to recover whey protein concentrates are the high costs, both capital and operating For the ultrafiltration operation alone, capital-related costs are about 40% of the total operating costs Membrane replacement costs are also high (15–30% of ultrafiltration operating costs) Most manufacturers guarantee a membrane life of 12–18 months and actual membrane life has been found to be from three months to more than three years

Ultrafiltration is a versatile unit operation, capable of producing a wide range of functional protein products,[155] and further growth in the production of ultrafiltered whey protein concentrates can be expected

4.5. Phosphate Precipitation

Under the appropriate conditions of concentration, pH, ionic strength and temperature many of the whey proteins begin to unfold and expose sulphydryl and hydrophobic groups This effect is enhanced by the presence of complexing agents and the proteins can be precipitated from solution Complexing of whey proteins as a means of isolation and recovery has received considerable study (see Table 3) but only phosphate complexes of whey (also known as lactalbumin phosphate) are available commercially at present, and these only in relatively small quantities

Long-chain polyphosphates precipitate whey proteins at low pH Phosphate chains, 50–60 residues long (0 5% concentration, pH 2 5) precipitate more nitrogen than trichloroacetic acid [156] The polyphosphate can be removed by neutralization and either precipitation by calcium ion addition, electrodialysis, ion exchange[157] or gel filtration [158]

In a typical process[159] a polyphosphate solution (for example potassium polymetaphosphate and sodium hexametaphosphate) is mixed with heated (55 °C) whey (300–900 mg/100 ml) acidified to pH 3 5, the precipitate recovered by centrifugation and washed The phosphate is precipitated from the complex by pH adjustment and the addition of calcium

Hidalgo *et al* [158] showed that calcium interferes with the phosphate precipitation reaction If the whey is demineralized by cation exchange, 70–90 % of the whey protein is precipitated by the addition of 50–100 mg hexametaphosphate/100 ml whey The composition of the precipitate, on a dry basis, is 70–85 % protein, 10–20 % hexametaphosphate and 10–15 % lactose Other variations of this procedure are described by Melachouris [160]

Commercial product, containing 30–85 % protein, is available as a powder, produced by spray drying the suspended or solubilized precipitate at temperatures below 70 °C Whey protein concentrates, produced by phosphate complexing, have moderate functionality but tend to be insoluble near the isoelectric pH [21] Because of the high cost of removing the phosphate they also tend to have relatively high mineral concentrations and, in many food systems, the phosphate has an adverse effect on the functional properties

4 6 Gel Filtration

Gel filtration is a chromatographic or molecular sieve procedure for separating substances on the basis of molecular size [161–164] Small molecules, such as whey salts and lactose, can permeate the solvent in the gel phase but larger molecules, such as protein, are partially or completely excluded and are eluted more rapidly Gel filtration is essentially a batch process in which the whey is applied to the gel, the proteins eluted with deionized water the remaining whey components eluted, the whey applied to the gel again and the cycle repeated Three modes of operation are described [163 164] column, centrifugal and annular

Commercial column operation is described by Lindquist and Williams [165] Whey, pretreated to remove lipid and solids, is concentrated by evaporation at 78 °C (although reverse osmosis and ultrafiltration have also been proposed) to about 20 % total solids, centrifuged and filtered to remove precipitated solids, and applied to the column at 55 °C In general, two fractions are eluted from the column with deionized water—a high molecular weight fraction containing the protein and a low molecular weight fraction containing lactose and salts The cycle times are of the order of 20–30 min and the use of a number of columns gives essentially a

continuous operation The high molecular weight fraction (1–2% total solids) is concentrated by evaporation and spray-dried Depending on where the cut is made between the high and low molecular weight fractions, product containing 30–80% protein can be obtained Protein yield is about 65% of the protein present in the initial whey for a 75% protein powder and increases (up to 90%) for lower (40%) protein-containing products

In another commercial operation,[25 166 167] whey was pretreated[138] to remove lipid material and suspended solids, concentrated to 50% total solids, lactose removed by crystallization, and the mother liquor, diluted to 20% total solids, applied to the gel Delaney *et al* [163] stated that basket centrifuge gel systems[168 169] were being used but Grindstaff[167] referred to columns This process produced three protein products, one of 50% protein and two with about 15% protein This operation has now been abandoned

The drawbacks of gel filtration are the high capital cost, the low concentration of protein in the eluate from the gel, the problems of controlling microbial growth and the difficulties of cleaning the gel, particularly after fouling by protein, calcium phosphate or lipid Only small quantities of whey protein produced by this process have been available commercially, despite the high expectations in the early 1970s

4.7. Adsorption

Whey proteins are amphoteric molecules and may be considered as charged ions At a pH lower than their isoelectric point whey proteins have a net positive charge and behave as cations which can be adsorbed on cation exchangers At a pH above their isoelectric point the proteins have a net negative charge and behave as anions which can be adsorbed on anion exchangers Media with suitable pore sizes and surface characteristics have been developed specifically for recovery of protein from dilute solutions and a number have reached pilot-scale or semi-commercial operation Suitable media have been prepared from regenerated cellulose,[170] titania, alumina[171 172] and silica [173]

In the 'Vistec' process using regenerated cellulose[170 174] the whey proteins are adsorbed at pH 3 2 and desorbed at pH 9 0 The adsorption and desorption are performed in stirred tank reactors fitted with filters The dilute protein solution (1%) is concentrated by ultrafiltration (which also results in a reduction of the mineral content) and evaporated before spray-drying Protein yield from whey is improved by demineralization or by ultrafiltration (to 1 5% protein) of the whey prior to adsorption

In the 'Spherosil' process,[175–177] silica-based resins are used in columns

Whey is passed through the column and the proteins are adsorbed When the resin is saturated, it is washed to displace the deproteinated whey and the proteins are eluted For acid whey at pH 4 4, the proteins are all in cationic form and are adsorbed by a suitable strongly acidic cation resin (containing reactive $-SO_3H$ groups) The adsorbed proteins are eluted with ammonium hydroxide (0 1 M) For sweet whey most of the proteins are in the anionic form and are adsorbed by a strong anionic resin ($-N(CH_3)_3^+Cl^-$) and eluted with hydrochloric acid (0 1 M) However, immunoglobulins are not adsorbed under these conditions and a second column with a weak cationic resin (—COOH) is used The immunoglobulins are eluted with ammonium hydroxide

The proteins are obtained in solution at a concentration of 2–5 % They are concentrated further by ultrafiltration and evaporation before spray-drying The Spherosil process recovers up to 90 % of the protein in the whey Some of the proteose-peptone and non-protein nitrogen components are also extracted

Whey protein concentrate powders recovered by ion-exchange adsorption techniques are characterized by high (>90 %) protein and low (<0 5 %) lactose and lipid concentrations and are claimed to have high functionality The column technique, in particular, also offers the prospect of protein fractionation, allowing specific proteins to be recovered in a purified form This method, though still only at the advanced pilot-scale stage, shows promise as a means of producing specialized proteins of high purity

4 8. Lactalbumin

The product precipitated from whey by heat denaturation is known traditionally as lactalbumin Early production was as a by-product from lactose manufacture, but more recently, particularly in New Zealand, production of lactalbumin has become significant, independent of lactose manufacture

The effect of increasing temperature on whey proteins has been extensively studied [10 11 14 178–186] When the whey proteins are heated they denature as their globular structure unfolds to a more random structure The sulphydryl groups of the whey proteins are exposed during heating so that aggregation can occur, particularly in the presence of calcium The effects of temperature and time on the precipitation of proteins from casein whey are shown in Fig 11 A minimum holding time of 10 min at 90°C was found necessary for maximum protein precipitation At the natural pH (4 6) the yield was approximately 75 % of the protein in

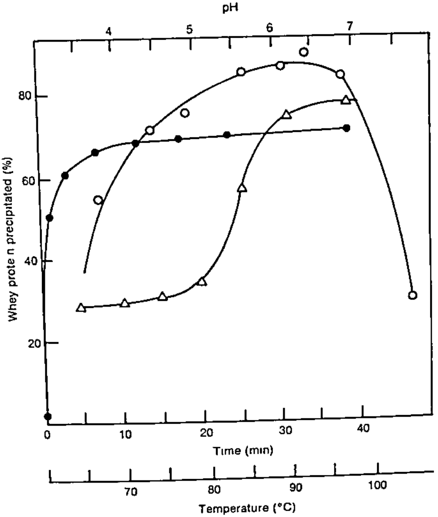

FIG 11 The effects of pH (holding time 1 h, 93 °C) ○, holding time (93 °C, pH 4 5), ●, and temperature (holding time 12 min, pH 4 5), △, on the yield of lactalbumin from casein whey [185]

the whey As the pH of the whey was raised to approximately 6 3 the yield of protein increased to 90% However, the mineral concentration in the precipitate increased as the pH was raised

Calcium is required for the coagulation of denatured whey proteins at pH values greater than 6, although the reaction only occurs at high temperatures [187] Rennet casein and cheese wheys give a maximum protein precipitation at pH 4 5, whereas for acid whey the maximum precipitation occurs at pH 6 5 When the calcium concentrations of the rennet and cheese wheys are increased, both types of whey behave in a manner similar to that of acid whey [188]

Commercial methods for the production of lactalbumin vary, depending on the type of whey and the final product required[185,186,189–191] (Fig 12)

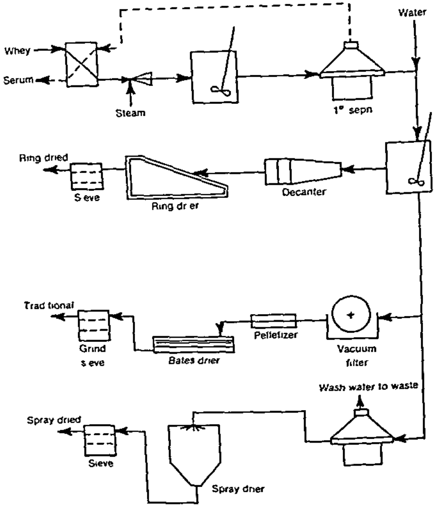

FIG 12 Process flow sheet for the production of lactalbumin showing alternative methods of dewatering washed precipitate from the first separation, and drying methods (Hobman, private communication)

Whey is heated, with or without pH adjustment (normally pH 4 6 or about pH 6 0–6 5 are used) to above 90 °C for longer than 10 min to denature the protein If necessary the solution is adjusted to pH 4 6 to coagulate and precipitate the protein, which is recovered by settling and decanting, or centrifuging The precipitate has high concentrations of minerals and lactose, which if necessary can be removed by washing with water The washed precipitate is dewatered by settling, centrifuging or filtering prior to drying using fluidized-bed, pneumatic-conveying ring, roller or spray-driers The dried product is ground, blended and packed The early stages

of this process are similar to those employed in the 'Centriwhey' process to increase cheese yield [74-77]

In a variation of the basic process, Cheddar cheese whey was treated in a cation exchange column, blended with raw whey to reduce to pH 4 5, and then heated [192] Improved processing was claimed for demineralized whey [193 194] Prior concentration to at least 15–18% total solids before heating could be employed to reduce the volume of liquid that must be heated Variable effects on the yield after concentration by evaporation have been reported [39,194-197] Concentration by reverse osmosis and ultrafiltration, both before and after heating, have also been studied [194 198] Modler and Emmons[197] heated whey to 95°C at pH 2 5–3 5 and adjusted the solution pH to 4 5 before precipitation The dried product from this process was soluble, particularly above pH 5 0

A pilot-scale, continuous process has been described [200] Coagulation was at 120°C with an average residence time of 8 min at pH 6 To increase the protein content of the precipitate above 65%, the cooled slurry can be adjusted to pH 4 5 (thus resolubilizing the calcium salts) prior to centrifuging Even higher protein contents (up to 95%) can be obtained by washing the centrifugate

A detailed discussion of the methods of recovery of the precipitated lactalbumin is contained in the reviews by Robinson *et al* [185] and Greig [186] Modern plants use self-desludging centrifuges to recover the precipitate prior to washing Self-desludging centrifuges are used to dewater the washed slurry Horizontal solid bowl decanters are being used for this duty also (Hobman and Retter, private communication) Lactalbumin slurries are dried in spray-driers (feed to drier 14–16% total solids), roller driers (15–24%) or pneumatic-conveying ring driers (20–30%) Casein driers of the tunnel, Bates or Pillet type can be used, provided filtration is used to produce a cake of 24–30% total solids which is pelletized before being fed to the drier (Fig 12) The yield of protein varies from 45 to 80% of the protein in the whey, depending on the conditions used The precipitate contains from 45 to 90% protein on a dry basis, depending on the pH of precipitation and the degree of washing Product yields range from 4 8 to 8 3 kg/m^3 of whey

Lactalbumin is finding an increasing range of uses[185 186] particularly in cereal-based foods requiring nutritional supplementation Whilst traditional lactalbumin does not retain the functionality of the native proteins, the nutritive value is high and continued production can be expected

5. CONCLUSIONS

During the last 20 years there has been a marked growth in the processing of whey to produce marketable human and animal foods However, nearly half the whey is still being wasted and there is a considerable potential for further growth in the production of whey-based products Pressure from legislative authorities to reduce pollution of natural waterways and the desire of the dairy industry to increase its economic returns, continue to promote the commercialization of whey processing research studies

Most of the whey solids that are being processed are being recovered as whole whey, either as whey concentrates or powders Smaller quantities of whey solids, particularly proteins, are being recovered in cheese and co-precipitates and with microbial protein With the growing sophistication of separation techniques, whey powders are being upgraded using such methods as lactose crystallization, electrodialysis and ion-exchange Sophisticated unit operations are making it possible also to recover the whey proteins with their functional properties intact, but only ultra-filtration is finding wide scale use at present Phosphate and other complex precipitation techniques show little advantage over other methods of whey protein isolation and will find use only in specialized end-products The use of gel filtration is unlikely to grow unless there is a major breakthrough in technology, similar to the advent of reliable non-cellulose membranes for ultrafiltration Adsorption techniques, while still only at the pilot scale, show considerable promise because of the high purity of the proteins produced and the potential ability to fractionate proteins Relatively high projected capital and operating costs may hinder rapid growth of this technology

The future for whey proteins, particularly whey protein concentrates, is not clear The potential is very great, but, before this can be realized, a deeper knowledge is required of the complex physical chemistry of the whey proteins, both in their reactions during the isolation procedures and in their interactions with other food ingredients

The growth of whey protein isolation methods is also dependent upon a recognition and use of the unique functional properties of these proteins Whey protein concentrates are being used frequently as replacements for skim milk or non fat dried milk solids, because they often have a cost advantage as a result of the support prices paid for milk powders This is a constantly changing market, and, until whey protein concentrates achieve an identity of their own, their widespread use by food processors will be constrained

The food processor is faced with a wide range of whey protein products, each with unique properties. It is probable that the market impact of these products could be increased if whey processors limited the range of products presented to the market However, this limitation must not be at the expense of reduced flexibility and a reduction in the ability to tailor-make whey proteins for specific end-uses

A significant economic factor limiting the production of whey protein concentrates is the need to process the deproteinated serum This serum retains most of the components of the whey which could cause pollution and many avenues are being studied to determine means of using these non-protein whey solids [202, 203]

Continued fundamental studies of the physical chemistry of whey proteins, coupled with vigorous co-ordinated technical marketing of the protein products isolated from whey, will be needed if commercial whey protein isolation methods are to continue to grow

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Chapter 12

FUNCTIONAL PROPERTIES OF MILK PROTEINS AND THEIR USE AS FOOD INGREDIENTS

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1. INTRODUCTION

The functionality of milk proteins is essential to the processing and production of most commercial milk products. Milk protein functionality is beyond the scope of this discussion, but general treatments of the subject are provided in previous chapters of this book as well as in other references.[1-4]

The fundamental properties of caseins and casein micelles in milk, as influenced mainly by compositional factors such as protein concentration, pH, ionic composition, and temperature, heating and enzyme treatments, all play important roles in providing physical stability to the total milk colloidal and emulsion systems.[5] The susceptibility of whey proteins to denaturation and aggregation in highly heated and dehydrated milk products is also a function of the above factors. In addition, the caseins undergo substantial alterations in physicochemical properties due to processing treatments required to isolate them from milk, as do the whey proteins.[6,7] For example, adjusting the pH of milk to 4.6 with acid to precipitate the caseins and subsequent neutralization with alkalis to produce caseinates, completely disrupts the colloidal phosphate matrix of native casein micelles and thereby alters the physicochemical properties of the resulting product. Treatment with rennet-type enzymes results in specific hydrolysis and alteration of the physicochemical properties of the caseins without disrupting the colloidal phosphate matrix.[5] Co-precipitation of casein micelles and denatured whey proteins, which had interacted via disulphide interchange during the high heat treatment, undoubtedly

alters the physicochemical properties of both proteins It is therefore understandable why each of the different milk protein products exhibits unique physicochemical and functional properties in food applications

2. GENERAL AND FUNCTIONAL REQUIREMENTS OF FOOD PROTEIN PRODUCTS

Commercial milk protein products, e g caseins, caseinates, casein–whey protein co-precipitates, whey protein concentrates and isolates and lactalbumin, all meet the general requirements listed in Table 1 for food protein products and ingredients [8] They also meet a number of the functionality requirements (Table 2) for food proteins [8 9] For example,

TABLE 1

GENERAL REQUIREMENTS FOR FOOD PROTEIN PRODUCTS[a]

Free of toxic/anti nutritional factors
phytate, flatulence factors, enzyme inhibitors, microbial toxins, pathogenic micro-organisms, toxic amino-acid derivatives
Minimal off-flavour and colour
High protein concentration
Compatibility with other ingredients/processing conditions
Protein functionality
Nutritional quality
Ready availability and low cost

[a] Adapted from Morr [8]

TABLE 2

FUNCTIONAL REQUIREMENTS OF FOOD PROTEIN INGREDIENTS[a]

Property	*Functional attribute*
Organoleptic	Flavour, odour, texture, colour
Appearance	Turbidity, colour
Hydration	Solubility, dispersibility, swelling, viscosity, gelation
Surfactant	Emulsification, foaming, whipping, baking
Structural	Elasticity cohesion, texturization, aggregation
Textural	Viscosity, adhesion, aggregation, texturization, gelation
Rheological	Aggregation, gelation, viscosity, dough formation, extrudability
Other	Compatibility with other ingredients and with processing conditions

[a] Adapted from Morr [8]

milk protein products generally possess excellent nutritional quality, flavour and colour if processed and stored under conditions that minimize Maillard and oxidative chemical reactions

3. CASEINS AND CASEINATES

The functionality of caseins and caseinates is closely related to their physicochemical properties [10] A brief consideration of this subject is provided below, but the reader is referred to previous chapters for additional details

3.1. Physicochemical Properties of Casein

Perhaps the most significant aspect of the primary structure of the casein subunits, e g α_s-, β- and κ-caseins, is their large and uneven distribution of acidic (carboxyl and ester phosphate) and hydrophobic amino-acids along their polypeptide chains As indicated by Bloomfield and Mead,[11] this phenomenon leads to highly charged polar and highly hydrophobic regions on their molecular conformation, thus resulting in amphiphilic properties which are highly susceptible to intermolecular interactions and polymerization through hydrophobic and Ca^{2+} bonding Slattery[12] developed conformation models for each of the major casein subunits Inherent in his models is the consideration that a uniform distribution of proline residues along the polypeptide chains of the caseins is responsible for their random coil conformation with little helical content His models also depict the casein subunits as compact, prolate ellipsoids containing most of their hydrophobic residues in one region of the polypeptide chain, plus an acidic region containing most of the carboxyl and serine phosphate groups The compact hydrophobic region is apparently stabilized by intramolecular hydrophobic bonding while the acidic region of the molecule is exposed to the aqueous phase and available for interaction with adjacent molecules through ionic and Ca^{2+} bonding Additionally, κ-casein contains two half-cystine groups and a glycomacropeptide group that provide additional mechanisms for interaction with other caseins as well as with whey proteins under appropriate treatments and processing conditions [5]

Consideration of the above conformational models of the casein subunits is useful in attempting to understand fundamental differences in their functionality in various food applications The three major caseins exhibit strong interactions at neutral pH, especially in the presence of Ca^{2+} ions, presumably through cross-linking of carboxyl and ester phosphate

groups, as well as through intermolecular hydrophobic bonding that is favoured at appropriate conditions of temperature, pH and $[Ca^{2+}]$ [13]

The acidification and neutralization treatments employed for precipitation and resolubilization (Fig 1) remove the colloidal phosphate matrix that stabilizes native casein micelles in milk. The resulting protein system consists of polymerized casein subunits that are probably arranged in an ordered structure that allows maximum interaction through hydrophobic bonding and also retains the polar, acidic groups in an exposed position where they can be readily influenced by pH and ionic composition of the medium [14,15] Such re-formed casein polymers bear little resemblance to

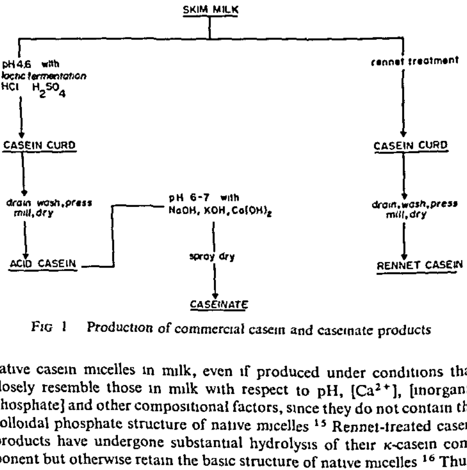

FIG 1 Production of commercial casein and caseinate products

native casein micelles in milk, even if produced under conditions that closely resemble those in milk with respect to pH, $[Ca^{2+}]$, [inorganic phosphate] and other compositional factors, since they do not contain the colloidal phosphate structure of native micelles [15] Rennet-treated casein products have undergone substantial hydrolysis of their κ-casein component but otherwise retain the basic structure of native micelles [16] Thus, commercial casein and caseinate products exhibit a spectrum of physicochemical and functional properties that can be matched to the requirements for a number of different food products

3 2. Commercial Casein Products

The historical and current status of casein and caseinate products manufacture and utilization has been reviewed[17-19] (see also Chapter 10 of this book) Annual production of these products is approximately 120 000 tonnes on a worldwide basis, most of which is produced in New Zealand and Australia [20]

A variety of different casein and caseinate products is produced, including acid (hydrochloric, lactic and sulphuric) casein, rennet casein, caseinates (sodium, potassium and calcium) and casein–whey protein co-precipitates Lactic casein is produced by fermentation of pasteurized skim milk with *Streptococcus lactis* or *S cremoris* cultures to achieve a pH of 4 6, the isoelectric point of the caseins Hydrochloric acid and sulphuric acid caseins are produced by direct acidification with the respective acids to obtain pH 4 6 Rennet casein is produced by treating skim milk with rennet-type enzymes to modify the κ-casein component of the casein micelles resulting in the formation of a gel structure, as in the manufacture of cheese These casein products are processed to expel and drain the whey, washed with water, drained, pressed, milled, dried, ground, sieved and bagged (Fig 1) All of these processing steps are essential in order to produce a protein product with adequate flavour stability The caseinates are produced by treating acid casein curd with NaOH, KOH or $Ca(OH)_2$ to resolubilize it and convert the casein subunits to their corresponding salt form at pH 6–7 [21] The resulting caseinate sol is spray dried, sifted and bagged Casein and whey protein co-precipitates are produced by a variety of processes that generally involve heating skim milk to >90 °C to denature substantial amounts of the whey proteins and complex them with the κ casein component of casein micelles by disulphide interchange, thereby rendering the entire milk protein system precipitable upon acidification to pH 4 6 or by addition of Ca^{2+} ions The resulting protein precipitate, consisting of about 10–20 % whey proteins, is then drained, washed and further processed as for casein products [21] Although co precipitates have been produced containing casein and other protein sources (e g from cereal, oilseed and egg), casein and whey protein co precipitates are the only products being manufactured and used on a commercial scale

3 3 Composition and Physicochemical Properties of Caseins and Caseinates

The general composition of commercial casein and caseinate products is given in Table 3 Obviously, variations are expected in the composition of these products due to the use of different processing conditions in their

TABLE 3
APPROXIMATE PERCENTAGE COMPOSITION OF COMMERCIAL CASEIN AND CASEINATE PRODUCTS*

Component	*Sodium caseinate*	*Calcium caseinate*	*Acid casein*	*Rennet casein*	*Co-precipitate*
Protein, N × 6 38 (min)	94	93 5	95	89	89–94
Ash (max)	4 0	4 5	2 2	7 5	4 5
Sodium	1 3	0 05	0 1	0 02	—
Calcium	0 1	1 5	0 08	3 0	—
Phosphorus	0 8	0 8	0 9	1 5	—
Lactose (max)	0 2	0 2	0 2	—	1 5
Fat (max)	1 5	1 5	1 5	1 5	1 5
Moisture (max)	4 0	4 0	10	12	5 0
pH	6 6	6 8	—	7	6 8

* Data from New Zealand Milk Products Inc [22]

manufacture, as well as to the need to alter specifications according to the requirements of the user The major differences in composition of the above products are in their mineral contents, which result from variations in processing treatments used to precipitate and solubilize the caseins For example, casein products that retain colloidal phosphate have higher calcium and phosphorus contents than those that have been subjected to isoelectric pH precipitation Also, the selection of the alkali solution used to neutralize the casein sol greatly affects the amount of that particular ion in a caseinate product

Caseinates are valuable ingredients in many food applications because they are completely soluble at pH values above 5 5 at normal Ca^{2+} concentrations Calcium caseinate forms stable colloidal dispersions rather than solutions in water [22] Neutral pH solutions of sodium caseinate are stable to heating at 140°C for 15 min, but the heat stability of calcium caseinate dispersions is a function of protein concentration and pH [22] At concentrations above 4%, calcium caseinate dispersions are stable to heating at 120°C for 15 min at pH above 7 Sodium caseinate solutions exhibit higher viscosities than calcium caseinate dispersions under comparable solution conditions, e g sodium caseinate sols form gels at concentrations above 17% but calcium caseinate dispersions do not Sodium caseinate is more effective as an emulsifier, thickener and foaming agent and absorbs water more effectively in wheat flour systems than does calcium caseinate [22] Lactic casein absorbs less water than either of the above caseinates [23] Rennet casein is solubilized at pH > 9 in the presence of

Ca^{2+}-complexing chemicals such as sodium tripolyphosphate The viscosity of the resulting solution of rennet casein is a function of the casein/polyphosphate ratio,[22] rennet casein dispersions at concentrations above 15% have mild gelling properties at temperatures around 25 °C Viscosities of rennet casein dispersions undergo a gradual reduction with increasing temperature in the range 25–60 °C [22] Rennet casein dispersions are extremely sensitive to Ca^{2+} concentrations of the order of 0 003 %, which is about 2 % of the original amount in native casein micelles Rennet casein dispersions are relatively heat-stable under appropriate pH and [Ca^{2+}] conditions Rennet casein contains approximately 2 8 % calcium and 1 4 % phosphorus, derived mainly from the colloidal phosphate of casein micelles, these are in about the same ratio as in milk Rennet casein, like the other casein and caseinate products, exhibits satisfactory flavour stability when handled properly The flavour defects that develop in rennet casein are generally less objectionable than the gluey, musty flavours common in aged acid caseins and caseinates

Casein and whey protein co-precipitates, which contain about 10–20 % whey proteins,[21] exhibit higher protein efficiency ratios, >2 7, compared with ~2 5 for caseins and caseinates [22] Co-precipitates are produced to contain a range of calcium contents to provide variability in their physicochemical and functional properties Co-precipitates can only be dissolved at alkaline pH or in polyphosphate solutions [21] The solubility of low-calcium co-precipitates resembles that of casein over a range of pH values but medium- and high-calcium co-precipitates require Ca^{2+}-complexing agents, e g polyphosphates, to provide complete dissolution at neutral pH Water absorption values for the different co-precipitates exhibit considerable variability, e g from 111 to 345 g water absorbed per 100 g protein, compared with values of 115 for lactic casein and 295 and 159 for sodium and calcium caseinates, respectively [23] Only limited information is available for physicochemical properties of co-precipitates other than that on water absorption in bread dough formulations

3.4. Functional Properties of Caseins and Caseinates

Caseins and caseinates contribute excellent nutritional value to food products but their principal value in most foods is their functional contributions Functional properties provided by caseins include water-binding-absorption, fat binding, viscosity and gelation, whipping and foaming, emulsification and texturization [17–21] They are important components in breakfast cereals, baked foods, comminuted meat products, whipped toppings, coffee whiteners, desserts, instant breakfast bars and beverages,

puffed snacks and cheese analogues[17-21 24] They are also important components of commercial protein blends formulated from whey proteins, soy proteins, cereal and other protein sources for baking, frozen dessert and other food applications that normally use non fat dry milk or caseinate alone to provide nutritional and functional contributions Since much of the specific information on the use and functionality of caseins and caseinates has been developed by food companies, it is of a proprietary nature and not available in the literature

Although early use of caseins and caseinates in food products was primarily in comminuted meat products, newer applications have been developed in a number of food product lines, especially those that require excellent surfactant properties, e g coffee whiteners, whipped toppings, low-calorie margarines and desserts Recent developments in cheese analogues utilize their unique textural properties that simulate those of processed and Mozzarella-type cheeses

Caseins and casein micelles exhibit higher emulsion interface activity than native whey proteins[25] and their excellent surfactant properties are probably due to the amphiphilic molecular conformation of the subunits that enables them to provide simultaneously both hydrophilic and hydrophobic groups at the oil–water interface [21] Further, it appears that the highly structured caseinate and casein polymers possess the ability to dissociate| rapidly and emulsify fat globules during high pressure homogenization, as well as to protect air cells as they are formed in aerated food products [26 27]

The emulsification properties of caseinate and non fat dry milk have been compared as a function of pH and ionic strength [28] Caseinate provides good emulsification under all pH and ionic strength conditions studied, e g from pH 5 6 to 10 4 and at ionic strengths up to 0 3 M, but was especially effective at the higher range of pH values Casein micelles in non fat dry milk exhibited better emulsification properties under all conditions studied but were most effective at the lower pH values It appears that pH influences the functionality of casein micelles in non fat dry milk by a different mechanism from that for caseinates Acid pH treatment should disrupt the colloidal phosphate in the casein micelles, which would result in a profound alteration of their conformational state In addition, acid pH conditions should promote casein subunit polymerization [5 15] The effect of changing pH on emulsion stability would also be a factor in altering the electrostatic charge on dispersed fat globules, which would in turn influence adsorption of casein subunits, micelles and ions from the solution It is likely that the higher Ca^{2+} ion concentration in

non-fat dry milk emulsion systems, provided by dissolution of the colloidal phosphate of the casein micelles, would alter the emulsification properties of the casein subunits and polymers

The emulsification properties of caseinate in model emulsion systems containing added chemical emulsifiers varying in HLB number have provided additional information upon the interaction with other food components, on the functionality of milk proteins [29,30] Caseinate exhibited variable emulsion stabilization properties under the influence of Ca^{2+} ion concentration and added emulsifiers The presence of Ca^{2+} and HLB 3–5 emulsifiers improved emulsion stability but added citrate ions reduced emulsion stability These findings indicate that ionic constituents and chemical emulsifiers result in significant alterations of functionality of caseinate and further confirm the need to define the experimental conditions used to evaluate protein functionality It is essential to investigate functionality of proteins in model systems that closely resemble the actual food system in order to obtain reliable and meaningful results for developing new or improving existing food products

Sodium caseinate dispersed in NaCl solutions of ionic strength 0 2 at pH 7 exhibited higher emulsion stabilities when processed under low and moderate homogenization intensity–time conditions than caseinate dispersed in distilled water, i e ionic strength 0, at pH 7 [31] Comparable emulsion stabilities were produced at high intensity–time homogenization conditions for both caseinate dispersions Thus, it is important to control adequately the processing conditions employed to investigate the functionality of proteins in order to obtain meaningful results The processing conditions used for model functionality studies must closely resemble those to be employed in formulating and producing the actual food product In addition, it is essential to include investigation of the influence of processing treatments upon the basic physicochemical properties of the protein system in order to be able to understand the fundamental basis for observed functionality performance and to gain the ability to predict the influence of other components, alteration of dispersing medium composition and processing treatments upon the functionality of the protein system

Casein–whey protein co-precipitates are especially useful in the formulation of breakfast cereal, snack and pasta products since their low solubility allows them to contribute characteristic textural properties to these products [20] The flavour of co-precipitates is a concern and limitation to their use in certain food products as they normally exhibit significant levels of Maillard and disulphide interchange reaction-type flavours

common to highly heated milk products [21] These protein products are commonly used in baked foods and cereal products where they contribute nutritional value without adversely affecting the flavour As indicated above, improvement of the solubility of co-precipitates is accomplished at alkaline pH and by addition of polyphosphates These conditions could also be used to improve those functional properties that are dependent upon solubility, such as emulsification and gelation Co-precipitates are being used in comminuted meat products where they contribute to the water- and fat binding properties of the meat proteins Other food product applications include dairy spreads, cultured dairy products and other food products where they contribute viscosity, texture and other desirable properties [21]

4. WHEY PROTEINS

Cheese and casein wheys contain about 20 % of the total milk proteins and their recovery and use in food products is the subject of considerable interest throughout the developed nations of the world Although lact-albumin, a highly heated whey protein product, has been available for a number of years, it has limited solubility and functionality for most food applications Thus, the industry is giving much attention to newer processes for recovering the whey proteins in a more functional state, such as in whey protein concentrates[7 8] and more recently as whey protein isolates [32–34]

4 1. Commercial Whey Protein Products

Since undenatured whey proteins are not precipitated at their isoelectric points, as are the caseins, it is necessary to resort to other fractionation techniques (Fig 2) to isolate them from whey, e g ultrafiltration–reverse osmosis, gel filtration, or precipitation as polyphosphate or carboxy-methylcellulose complexes [7] Although ultrafiltration is currently the method of choice,[35] it too presents major limitations that have not been resolved, e g membrane fouling, low flux rates, prolonged exposure to elevated temperatures with its associated problems due to microbial contamination and protein denaturation, and incomplete removal of low molecular weight components Polyphosphate and carboxymethylcellulose —whey protein complexes exhibit limited functionality, especially below pH 7 because of residual protein precipitant in the final product [6]

Since there are at present no standards of identity for whey protein

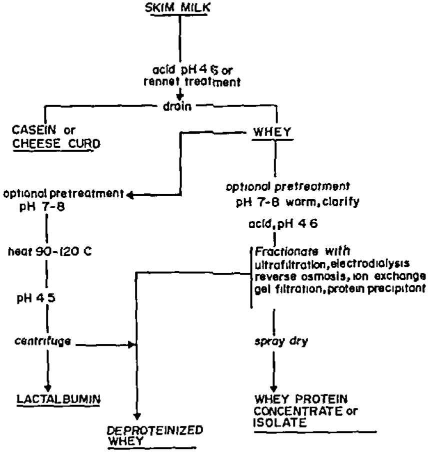

FIG 2 Production of commercial whey protein products

products, the term 'whey protein concentrate' is generally used to designate all whey protein products with increased protein levels over those in dried whey Additional terms used by the US Department of Agriculture are 'partially delactosed whey', 'partially demineralized whey' and 'partially delactosed, partially demineralized whey' Whey protein concentrates being produced and used by the industry commonly contain up to 50% protein Thus, they obviously retain significant levels of residual lactose, milk salts and other non-protein components of whey that limit the utility of the product for use in foods Even though it is theoretically possible to produce whey protein concentrates with higher protein concentrations, even up to an isolate status, i e 90% protein, such processes are not commercially feasible, mainly because of the disproportionately high cost of the extra purification effort Recent development of ion exchange processes indicate good promise for producing whey protein isolates with 90% protein content, but these processes have not yet attained commercial status [32-34]

As indicated above, lactalbumin has been available for some time for use

in certain food products such as those listed for casein–whey protein co-precipitates It is produced by adjusting the pH of whey to 4 5–5 2 and heating to temperatures above 90°C to precipitate 70–80% of the whey proteins [20]

4.2. Physicochemical Properties

Comparison of the primary structures of the important whey protein components, e g β-lactoglobulin and α-lactalbumin, with those of the caseins reveals several key differences which probably account for unique physicochemical and functional properties [10] For example, whey proteins contain lower concentrations of proline and hydrophobic amino-acids and no ester phosphate or sugar groups, but they contain higher concentrations of sulphur-containing amino-acids and a more even distribution of the different amino-acid types along their polypeptide chains [4] Thus, the whey proteins lack the amphiphilic properties of the caseins and also, due to their low proline content, they exhibit a compact, globular conformation with substantial helical content [35] This latter property probably accounts for their high susceptibility to heat processing and other agents that normally cause protein denaturation, loss of solubility and reduced functionality [5 6 8]

Heat denaturation of whey proteins causes unfolding of their globular structure to form a random coil conformation that is more susceptible to protein–protein interactions, e g self-aggregation via Ca^{2+} bridging, disulphide interchange and hydrophobic bonding, as well as interaction with κ-casein (in milk) via disulphide interchange [5] Although β-lactoglobulin and α-lactalbumin are capable of undergoing association–dissociation phenomena via hydrophobic and ionic bonding at low pH values,[36] such reactions are of minor importance, since few food applications of whey protein products occur at such low pH values Increasing protein and Ca^{2+} ion concentrations and exposure to elevated pH and temperature conditions increase the probability of whey protein denaturation and associated reactions that adversely affect their functionality In addition to heating, other processing treatments, e g pumping, mixing, aeration, vacuum evaporation and drying, further promote protein denaturation [6 7] It is, therefore, important to exercise care in handling whey protein products to retain maximum protein functionality It has been demonstrated, however, that controlled heating immediately before incorporation into food product formulation improves the foaming properties of whey protein concentrates [37 38] Such heat treatments may improve functionality by promoting limited protein denaturation or by disrupting

protein–lipid complexes, since it has been shown that residual lipids inhibit the foaming properties of whey protein concentrates and interfere with their gelling properties [37,39,40]

4.3. Composition and Properties of Whey Protein Products

The composition of whey protein concentrates and lactalbumin (Table 4) is quite variable and dependent upon the particular whey source, e g acid or sweet whey, and upon the fractionation technology employed in their production, e g reverse osmosis and ultrafiltration, gel filtration, protein complex precipitation, etc [6,7] As indicated above, processing parameters may be adjusted to produce whey protein products with up to 90 % protein but such modifications are accompanied by disproportionately high production costs

Care is necessary to minimize protein denaturation during pre-heating, vacuum evaporation, drying and related processing steps in the production of whey protein concentrates, since concomitant protein–protein and protein–ion interactions reduce solubility and related functionality, especially in the acid pH range or in the presence of moderate concentrations of Ca^{2+} and other polyvalent ions [6,7] The extent of protein denaturation is normally assessed by loss of solubility at the isoelectric point (pH 4 5–5), or by alterations in gel electrophoretic patterns [6] However, the presence of residual protein precipitant, e g metaphosphate or carboxymethylcellulose, as with certain whey protein concentrates, interferes with assay techniques for determining both protein solubility and denaturation Commercial whey protein concentrates normally exhibit significant amounts of protein denaturation, For example, they commonly display solubilities at pH 3 5–4 5 of 24 to 93 % and of 65 to 100 % at pH 6–8 [6,41] Experimental batches of whey protein isolate produced by ion exchange cellulose processing[33] had only 35 % protein solubility at pH 4 5, indicating that this process, because of either high temperature or pH conditions, causes a high degree of protein denaturation [34]

Variations in the available lysine content of whey protein concentrates are useful in estimating their heat exposure history[6,41] since heating and storage at elevated temperatures promote Maillard-type reactions that produce brown pigments and impart characteristic off-flavours to whey protein concentrates Values for commercial whey protein concentrates range from 4 5 mg/100 mg protein for electrodialysed whey protein concentrate, to 9–9 5 mg/100 mg protein for whey protein concentrates prepared by metaphosphate and carboxymethylcellulose precipitation

TABLE 4
PERCENTAGE COMPOSITION OF WHEY PROTEIN PRODUCTS

Component	*Whey protein concentrate*[a]					*Lactalbumin*[b]
	Ultra-filtration	*Gel filtration*	*Metaphosphate complex*	*CMC complex*	*Electro dialysis*	
Protein, N × 6 38	50–62	50–54	54–58	50	27–37	80–86
Ash	0 5–6	11–13	10–15	8	1 4–2 0	2 5
Lactose	15–40	25–37	13	20	40–80	7
Fat	1 5–15	0 8–2 0	3 3–7 3	1 2	2 4–4 3	5
Moisture	3–5	3–5	3–5	3–5	3–5	5

[a] From Morr *et al* [6]
[b] From New Zealand Milk Products Inc [22]

Buffer capacity data provide an indication of the types and concentrations of the important ions that are retained in whey protein concentrates.[6] For example, calcium metaphosphate whey protein concentrate gives a buffer capacity–pH curve very different from that of sodium metaphosphate whey protein concentrate, presumably due to variations in the levels of these two ionic species. Similarly, the buffer capacity–pH curve for electrodialysed whey protein concentrate is very different from that for whey protein concentrates prepared by ultrafiltration.

Whey protein concentrates contain sufficient residual lipids and phospholipids, as well as Cu^{2+} and other pro-oxidants, to be readily susceptible to development of gluey and related off-flavours during dry storage.[35] Storage under N_2 atmospheres, use of Cu^{2+}-complexing substances and anti-oxidants, results in some improvement but inclusion of an additional clarification treatment to reduce the lipid content prior to concentration by ultrafiltration provides the most effective improvement in flavour stability. As indicated above, removal of residual lipids is also important for improving foaming and perhaps other functional properties of whey protein concentrates.

Lactalbumin is a commercial whey protein product containing 80–82% protein which has been exposed to considerable heat processing during its production.[20] The product has poor solubility and is therefore functional in only a limited number of food product types where solubility is not an important property. Also, since the protein product has been exposed to such high heat conditions, it contains high levels of heat-induced Maillard-type pigments and flavour compounds which further restrict its use to those products that also contain or require these compounds. Although the product exhibits good water absorption, it undergoes physical alterations during drying that irreversibly reduce its ability to re-absorb water.[42]

4.4. Functional Properties of Whey Protein Products

The functionality of whey protein concentrates and isolates has been investigated in model food systems of varying degrees of complexity, from simple solutions to complex systems that closely resemble actual food products. Most applications require a highly soluble protein product with minimal levels of lactose, milk salts and other residual components from the original whey. Additionally, the protein ingredient must contribute adequate nutritional quality without adversely affecting the product's flavour, colour and physical properties. The proteins must also be compatible with other components and processing requirements, i.e. it must

not adversely affect clarity, viscosity, texture, appearance, heat stability and other important product characteristics

The functionality of whey protein products is dependent upon at least the following complex factors (a) physicochemical properties of the whey proteins arising from whey source and composition (acid or sweet whey), extent of protein denaturation and other types of deterioration, fractionation technology used and extent of protein re-hydration, (b) influences on composition and physical properties of the experimental or actual food system of (i) the types and amounts of ions and other proteins and their compatibility with whey proteins, and (ii) the types and reactivities of inherent or added chemical emulsifiers, polysaccharide stabilizer gums and other components that may alter the physicochemical properties of the whey protein, and (c) processing technologies for incorporating whey protein and the other products into the formulation, e g time–temperature–intensity of blending, mixing, whipping, emulsification

Whey protein concentrates exhibit variable emulsion stabilizing properties [6 8 41] In general, whey protein products exhibit inferior emulsification properties compared with caseinates, however, their emulsification properties are not as susceptible to fluctuations in pH as are those of caseinates and soy proteins [41] In addition to the above factors that regulate and control the general functionality of whey proteins, the following factors must also be considered in evaluating the emulsification properties of whey protein concentrates, or other proteins (a) emulsification methodology, e g high speed blending to produce a coarse emulsion[41] or high pressure homogenization to form a finely subdivided liquid emulsion,[6] (b) proportions of dispersed and dispersion phases, (c) physical properties of the fat/oil, e g solid fat index at the temperature of emulsification, (d) pH and ionic composition of the aqueous phase, (e) presence of chemical emulsifiers and other proteins or food components that interact with and modify physicochemical properties of the whey proteins, thereby influencing their ability to unfold and adsorb at the emulsion interface, and (f) the assay procedure to evaluate the emulsification properties of the protein, e g microscopic, centrifugal or measurement of gross changes in viscosity or electrical conductivity [26]

Since the source, composition and processing treatment history of each whey protein product to be evaluated for emulsification properties determines its physicochemical properties, it is essential that such information be considered These factors can be evaluated by determining molecular weight distribution by gel filtration chromatography, gel electrophoresis and other appropriate techniques If this information is not included in the

evaluation procedure, variations in emulsification performance of a given protein product merely reflect differences in the processing history of the protein rather than the important issue, i e. intrinsic emulsification properties of whey proteins in the food product

As with emulsification properties, the whipping/foaming properties of whey protein products are affected by a number of compositional and processing variables that include pH, Ca^{2+} concentration, redox potential, residual lipid content, protein solubility as influenced by whey composition, heat treatments, fractionation technology, drying conditions and the use of additives, e g phosphates, oxalates, chemical surfactants and sugars [8] In addition to the above factors, it should be emphasized that conditions employed during the whipping/foaming operation with respect to protein concentration, temperature, viscosity, time–intensity of whipping, type of whipping equipment and others are extremely important in obtaining a reliable assessment of the foaming properties of whey protein concentrates For example, in addition to controlling the total solids of the final formulation, it is also necessary to determine the actual protein concentration, since the protein level is quite variable among the different whey protein concentrate products Also, the presence of high lactose levels would undoubtedly interfere with the foaming functionality of the whey proteins Before the protein can function to stabilize foam cells, it must be in a soluble form Thus, the above discussion concerning the proper processing conditions and methods of assessing denatured and soluble proteins is also appropriate for this consideration Processing of whey protein products must include adequate clarification to remove effectively residual lipids which interfere with foaming function of the protein It appears that whey protein isolates that contain 95 % protein, 3 % ash and 0 5 % fat perform much better in foaming experiments than whey protein concentrates that contain 58 % protein, 4 % ash and 5 % fat [34] The role of the proteose-peptone whey fraction in supporting whey protein concentrate foams is still uncertain Results for deproteinated whey suggest that these peptide fractions are capable of contributing significantly to the foaming properties of whey protein products

Whey protein concentrates and isolates are capable of forming heat-induced gel structures under appropriate protein concentration, pH and ionic conditions [8 34 41 43 44] Heat-induced gels result from the formation of a three-dimensional protein–protein structure that physically entraps most of the free water [8] The gelation properties of the proteins are influenced by a number of factors (a) type of whey (sweet or acid) which affects lactose and ionic composition of the whey protein concentrate, (b)

physicochemical state of the protein as influenced by previous processing treatments, (c) protein/lactose and protein/mineral ratios, (d) Ca^{2+} and cystine concentrations, (e) processing conditions used to produce the gel and (f) pH of the system being investigated Gelation temperatures of whey protein isolates range from 56 to 58 °C as a function of pH from 7 to 9 and the water holding capacity, hardness and springiness of the resulting gels compare quite favourably with those for egg white protein [34] Thus, it appears that whey proteins can, under appropriate processing conditions, be used to produce gels that compare favourably with egg proteins, but the use of whey protein isolates with sufficiently high protein/lactose ratios will probably be required to produce gels with adequate textural properties

The relatively poor performance of whey and whey protein concentrates in baked food applications is probably due to high lactose contents and the inability of whey proteins to form firm gel structures [8 20] Reduction of the lactose content and the degree of heat processing to produce limited whey protein denaturation has resulted in some improvement in the functionality of whey protein concentrates in cake formulations Lipids, flour proteins, starch and other ingredients of the formulation probably interfere with the functionality of whey proteins in terms of their ability to form stable, heat-coagulable foam structures as effectively as egg white proteins Comparison of the physicochemical properties of whey proteins with those of egg albumin is useful in attempting to replace the latter proteins in baked food products [40] For example, knowledge of the minimum protein concentration, minimum coagulation temperature, influence of lipids, and variations in the amount of whey protein components among the different whey protein products is necessary to understand the basic conditions needed to utilize successfully whey protein products in baked food products Definite improvement in the functional performance of whey protein concentrate was obtained by incorporation of a chemical surfactant [40] More efficient removal of residual whey lipids by an additional clarification treatment effectively improved the functionality of whey protein concentrates in meringue products[35] but failed to induce a similar improvement in a biscuit product formulation Whey-based protein blends have been developed to replace non fat dry milk in baking applications [8] Such formulations usually contain caseinates, whey solids and soy proteins in proper proportions to simulate successfully the functional contributions of non-fat dry milk solids

There has been some interest in the use of whey proteins for nutritional fortification of soft drinks, many of which are carbonated [20 35] This particular application requires that the whey proteins and their mineral

components remain completely soluble at low pH and in the absence of other substances normally present in foods that stabilize against precipitation and settling

Other examples where whey proteins and their commercial products are commonly used in food formulations include baby foods, dietetic and therapeutic applications and cereal product nutrification [41]

It is clear from the foregoing considerations that whey protein products, i e concentrates and isolates, that contain sufficiently high protein concentrations in a predominantly undenatured form, with minimal lactose and lipid contents, are highly acceptable and functional protein sources for the food industry These products should be competitive with other major protein ingredients, e g caseinates, soy and egg protein products, for numerous food applications, assuming that they become more economically attractive

5. MILK PROTEIN MODIFICATION

Protein modification usually refers to physical, enzymatic and chemical treatments that alter primary and quaternary conformation and structure and related physicochemical and functional properties The subject of protein modification has been broadly reviewed[9] and critically considered,[45-50] and has attracted extensive research interest over the years

5.1. Processing Treatments

A number of commonly used processing treatments are employed to alter the physicochemical and functional properties of milk proteins in food processing [5] Some of these alterations are desirable but others are not, e g those arising from excessive heat treatments, use of alkaline pH values and drying The important processing treatments and their effects upon milk are summarized in Table 5

Cheftel[47] has reviewed the influence of processing and storage of food proteins on changes in their chemical and nutritional properties It is likely that exposure of milk protein concentrates and isolates to similar adverse processing and storage conditions causes similar modifications in their physicochemical and functional properties It is for these reasons that extreme care is needed during the isolation, storage and use of milk protein products to minimize such adverse modifications that reduce their general and functional properties (see Tables 1 and 2)

TABLE 5
PROCESSING-INDUCED MODIFICATION OF MILK PROTEINS

Process treatment	*Protein modification*
Heating	Interaction of β-Lg and κ-Cn via disulphide interchange
	Whey protein denaturation and aggregation
	Association of colloidal phosphate with casein micelles
	Aggregation of casein micelle/denatured whey protein complexes
	Maillard browning from interaction of ε-lysine and lactose
	Formation of cooked flavour from reactions of sulphydryl–disulphide groups
Acid pH	Dissolution of colloidal phosphate from casein micelles
	Precipitation of caseins and denatured whey proteins
	Conformational modification of whey proteins
Ionic adjustments	Stabilization of milk fat globule membrane proteins against feathering in coffee cream
	Alteration of heat stability of casein micelle in evaporated and sterile milk concentrates
	Alteration of physical thickening (gelation) of casein micelles in sterile milk concentrates
Rennet treatment	Hydrolysis of κ-caseins 105–106 peptide bond to form para-κ-casein and alteration of stability of casein micelles
	Curd formation in cheese and rennet casein manufacture
	Non-specific protein hydrolysis during cheese ripening
Microbial proteases	Hydrolysis of caseins to produce desirable texture and flavour during cheese ripening
Light exposure	Photopolymerization and degradation of whey proteins
Peroxide treatment	Oxidation of sulphur-containing amino-acids in whey proteins

5.2. Alkali Treatment

The effects of alkali treatments on proteins and the resulting alteration of chemical, physical and nutritional properties has been reviewed by Friedman [48,49] Such treatments catalyse racemization, β-elimination, and cross-linking of amino-acid residues in proteins In milk proteins, the β-elimination reaction involves amino-acid residues with —OH, —SH and

—OPO_3H groups[48,51] with the formation of lysinoalanine. The levels of lysinoalanine in commercial milk products and caseinates range from 0 to 6800 ppm.[52,53] Both intramolecular and intermolecular cross-links, which are not susceptible to digestion, are formed, thus resulting in alteration of the physicochemical properties, lower digestibility, reduction of nutritional quality and in some cases even in the formation of toxic factors.[54]

5.3. Peroxide Treatment

Certain protein products are subjected to hydrogen peroxide or benzoyl peroxide treatments, e.g. during the 'cold pasteurization/sterilization' of milk and whey, or during bleaching as in breadmaking.[47] These treatments cause oxidation of methionine and cystine/cysteine groups. For example, whey proteins are quite susceptible to a combination of peroxide (0.1–1.0%) and heat (<54°C) treatments[55,56] which cause complete destruction of β-lactoglobulin sulphydryl groups; all whey proteins undergo substantially more heat alteration on heating at 54°C in the presence of hydrogen peroxide than in control heated samples.

5.4. Enzymatic Modification

In addition to the above-mentioned use of rennet for the specific modification of κ-casein to form rennet casein or cheese curd, there is considerable interest in utilizing other proteinases to modify milk proteins.

The application of proteolytic enzymes to alter the solubility and functionality of proteins has been reviewed.[9,57] Extensive enzymatic hydrolysis of casein usually results in the production of bitter peptides which appear to contain high proportions of hydrophobic amino-acid residues, whereas limited casein hydrolysis products are not bitter. The bitter peptides may be removed from casein hydrolysates by any of several techniques. Perhaps the most significant technique is the 'plastein' reaction which involves treatment of casein hydrolysates with α-chymotrypsin to produce insoluble protein polymers with improved flavour.[58,59] Bitter peptides may also be removed from casein hydrolysates by treating with Duolite S-761,[60] hexylepoxy-Sepharose, LH Sephadex or activated carbon.[61] These latter treatments reduced the aromatic amino-acid content of the hydrolysates from both skim milk and casein.

Enzymatic hydrolysis has been employed to improve the solubility and functionality of whey proteins.[62,63] It appears that although these treatments result in substantial resolubilization of heat-denatured whey proteins, they are of only limited value for improving functionality. Commercial casein hydrolysates are used in sweets, whipped toppings and

other food product applications[17 64] Enzymatic hydrolysis of acid casein improves its solubility, but as noted above, results in pronounced bitterness[65] It is important to control the degree of hydrolysis by selecting the proper enzyme and temperature conditions and by monitoring the extent of hydrolysis in order to optimize the degree of casein modification A systematic attempt has been reported for defining and relating the functionality and flavour of protein hydrolysates to their degree of hydrolysis in terms of average peptide chain length[66] It should be possible to utilize immobilized enzyme reactor technology to improve the control of peptide chain length over that possible in bulk enzyme reactors

An additional application of enzymatic modification of caseins involves their dephosphorylation or phosphorylation by treatment with phosphatases and kinases[67] Such modifications results in dramatic alterations of casein solubility in the presence of Ca^{2+}, as well as of their isoionic points and electrophoretic properties

5.5. Chemical Modification

Chemical modification of food proteins offers potential for manipulation of their physicochemical and functional properties for food applications[9] Although chemical modification of a sort, i e conversion of casein to its sodium, calcium and potassium salts, has been practised for years, chemical derivatization of amino-acid residues in milk proteins has not been commercially attempted Perhaps the understandable reluctance of industry to risk production of a potentially toxic protein product is responsible for this lack of interest Other adverse factors such as reduced protein digestibility and nutritional quality due to cross-linking and destruction of essential amino acid residues, contribute to this lack of interest

Even though a number of nucleophilic groups on protein molecules are potentially susceptible to attack and derivatization by acylating reagents, the principal reaction sites are the α- and ε-amino groups[9] These acylation reactions replace cationic amino groups with neutral or anionic groups, thus altering the electrostatic charge on the protein and favouring subunit dissociation, loss of helical and globular structure, increased solubility, a decrease in isoelectric point and a reduced tendency to heat-induced gelation and coagulation[9]

Selected references are included to illustrate the possibilities of chemical modifications for improving the functionality of milk proteins Succinylation of heat precipitated whey proteins at pH 8 results in a substantial increase in water binding, viscosity and emulsification properties with little

apparent loss in nutritional quality[68] Although no work has been conducted to determine the toxicity of such derivatized proteins in humans, a similar acylated protein, acetylated casein, exhibited no apparent toxicity when fed to mice Other researchers have reported that the succinyl–lysyl bond in modified proteins is resistant to *in vitro* hydrolysis by trypsin but not by chymotrypsin[69] Acylated caseins and whey proteins exhibit good solubility down to pH 4 4 and are considered suitable for use in carbonated beverages[70] Although rats survived on diets in which most of the protein had been acylated, PER values were substantially lowered Thus, it appears that such proteins warrant further investigation before they can be used in human food products

Other researchers have trifluoroacetylated κ-casein and thereby altered its ability to stabilize α_s-casein in the presence of Ca^{2+}[71] Nitration of tyrosyl residues of κ- and α_{s1}-caseins reduces their abilities to complex but does not alter the calcium sensitivity of α_{s1}-casein[72] Esterification of the carboxyl groups of α_s- and κ-caseins with glycine methyl ester decreases the calcium sensitivity of α_s-casein and inhibits the ability of κ-casein to stabilize α_s-casein in the presence of calcium ions[73] Dansylation of κ-casein inhibits the ability of rennet to form a casein curd

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